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HIGH ALTITUDE STUDIES OF NATURAL, SUPPLEMENTAL AND DELETION OF UV-B ON VEGETABLES AND WHEAT

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FORWARD

Decisions having great impact must be made with regard to inadvertent modification of the upper stratosphere. It will be difficult to make such decisions due to insufficient hard data. Man's sustenance is at stake and thorough and rapid investigation is necessary.

There is need to know whether man's traditional food crops are adapted to enhanced levels of UV-B radiation which will result from stratospheric ozone depletion. The Colorado State University Horticulture group contributed to this interdisciplinary effort through research focused on enhancement of solar UV-B by means of filtered sunlamps as well as exclusion methods. These studies were conducted at high altitude with four crop species of international importance.

ABSTRACT

Our research was initiated in order to determine the influence of solar UV-B and solar supplemented UV-B radiation on wheat, *Triticum aestivum*; potato, *Solanum tuberosum*; radish, *Raphanus sativus*; pea, *Pisum sativum* and also to develop dose-response information including threshold UV-B levels for injury.

A field program was initiated at a site at 3000 m elevation, 39°11'N latitude and 106°56'W longitude located 43 km W of the Continental Divide and 11 km from the nearest highway.

Filtered sunlamps were employed in one experiment and UV-B transmitting films, a UV-B absorbing film, and 26% shade were used as treatments in another experiment. Plants were grown in containers in an artificial medium. Exposure began at emergence, June 23 and ended on August 13.

The only significant response by plants exposed to UV-B simulating at least a 20% reduction in ozone was that of stature reduction in wheat. It was discovered in the experiment where solar UV-B was supplemented with lamp UV-B that various factors associated with the technique preclude any rigid interpretation of the data.

Technical information regarding Aclar®, a UV-B transmitting film; lamp output relative to temperature; lamp variability; was gathered and a new approach to UV-B studies was suggested.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

UV-B	--irradiance in the 280-320 nm range
CA	--cellulose acetate film transmitting UV-B
AC	--Aclar film, transmitting UV-B
M	--Mylar film, does not transmit UV-B
U NL	--unlit or non-lamp, no emmission of energy
+UVB	--designation for treatments permitting UV-B
-UVB	--designation for treatments preventing UV-B
UV-A	--irradiance in the 320-400 nm range
PAR	--photosynthetically active radiation 400-700 nm range
AST	--apparent solar time
MDT	--mountain daylight time
BARC	--Beltsville Agricultural Research Center
UVBSE	--UV-B sun equivalents, a function of weighted (action spectrum applied) irradiance in the UV-B range - developed by BARC, UVBSE x 3.06 = weighted $mW.m^{-2}$ (280-320nm)
$A\xi 9$	--refers to actual equation $y = [0.25\ (\lambda/228.178)^{9.0}]\ \exp.\ [4-(\lambda/228.178)^{9.0}]$ and weights for biological effectiveness $\lambda<320$ nm, developed by BARC
FW	--fresh weight, not dried
DW	--dry weight - obtained by drying tissue in a forced draft oven at 70^{o} C for 48 hrs
14-14-14	--slow release fertilizer, 14% nitrogen + 14% phosphate + 14% potash

FS40	--Westinghouse sunlamp designation
nm	--nanometers
$mW.m^{-2}$	--milliwatts per meter squared
Error a	--whole plot error used to test $\pm$ UVB effect
Error b	--subplot error used to test irradiance and $\pm$ UVB x irradiance interaction
df	--degrees of freedom
MS	--mean square
LSD	--least significant difference, refers to mean separation
CdS	--cadmium sulfide
mmhos/cm	--a measure of conductivity and related to soluble salt concentration
pH	--$\log_{10}$ of the reciprocal of the H ion concentration, a measure of active acidity
mil	--2.54 mm 0.254 mm or 0.001 inches
bar	--750 mmHg or 99998 $N.m^{-2}$

SYMBOLS

R^2	--coefficient of determination, percent indicates the extent of variability in the dependent variable accounted for by the model
$Y = aX^b$	--general form for power model
$\bar{x}$	--arithmetic mean
*	--significant at 5% level
**	--significant at 1% level

P	--phosphorus
K	--potassium
Fe	--iron
Zn	--zinc
Cu	--copper
Mn	--manganese
Mo	--molybdenum
S	--sulfur
$NO_3 - N$	--nitrate nitrogen
$Ca(H_2PO_4)_2 \cdot H_2O$	--triple super phosphate
KNO_3	--potassium nitrate
$(NH_4)_2SO_4$	--ammonium sulfate
$NiSO_4 + CoSO_4$	--nickel sulfate plus cobalt sulfate, a liquid filter

ACKNOWLEDGEMENTS

We wish to acknowledge the continued cooperation of Aspen Skiing Corporation. Among other things, they provided the 3000 m site at the Snowmass Mountain Facility. We are particularly indebted to Mr. James Snobble, Mountain manager, and Mr. Robert Clark, Supervisor for their help including "emergency" type decisions made on the mountain. Ms. Ann McSay, Senior Research Technician in Horticulture deserves praise for her dedicated involvement in the project from beginning to end. We are happy to take the opportunity to thank the students both graduate and undergraduate who helped as they learned. They are Joseph Freeman, Debora Stevens, Tracy Sulzbach, Phoebe McCoy, C. Rajashekar and Robert Morris as well as Daniel Pskowski, Laurie Maxwell, Cheryl Hoffman and Douglas Drake. We also acknowledge the help of Thomas Knoblock a former student and resident of Aspen who provided handyman expertise when we needed it and Karen Hulse for data collection and analyses. A special note of appreciation goes to Dr. Frank Ronco of the U.S. Forest Service, former project leader of the spruce-pine investigation at the site. We wish to thank Dr. Ronco in particular for his design of the waterproof lamp fixtures and lamp structures and for the aid of his staff, Mr. Nelson and Mr. Ross.

Dr. Harry R. Carns, Chairman, Plant Physiology Institute USDA, ARS and his staff including Dr. Krizek and Mr. Rowan are acknowledged for their help particularly with the actual measurement of the UV-B irradiance on the mountain. Mr. Daniel Rowan actually spent a week with the IRL

Spec. D making measurements on the mountain. Mr. Michael Becwar, Ph.D. candidate and one of the authors of this report is to be congratulated for assuming full responsibility at the site so soon after he arrived from Oregon State University. Many thanks to Mrs. Jonilyn Hall for careful typing of the manuscript.

The Pitkin County Commissioners representing the most forward thinking community in the United States are hereby thanked for granting funds for research which was a prelude to the research carried out as described in the following pages of this report.

INTRODUCTION

Destruction of the stratospheric ozone due to increased concentration of halocarbons and nitrogen oxides could have serious impact. A problem is predicting this impact on food crops. Our study measured the magnitude of the impact caused by a realistic increase in solar UV-B radiation under natural outdoor conditions.

The study was unique in that the research took advantage of the naturally higher levels of solar UV-B radiation at high altitude. This was a primary method for increasing natural UV-B radiation levels. There are many difficulties in reproducing the natural levels of UV-B radiation using artificial light and some of these difficulties are reviewed by Sisson and Caldwell (1975). They point out that many of the difficulties are due in part to the increased effectiveness of shorter wavelengths of radiation which are present at such low levels. Artificial UV-B radiation generally has the wrong spectral distribution and intensity and therefore is not comparable to the natural solar radiation.

Radish and pea were chosen for this study because they originate at low altitude and because of this, we anticipated little innate UV-B radiation tolerance. Cline and Salisbury (1966) investigated the UV (254 nm) sensitivity of these two crops and found them to be sensitive and very sensitive, respectively. They were used for UV-B sensitive plants. Radish and pea have additional advantages in that they adapt well to the cool climate and short growing season at our high altitude research plot. Ergasheve et al (1971) reported photosynthetic impairment in pea seedlings

attributable to high elevation UV. Potato was chosen because it may be naturally more UV-B tolerant. Potato orginates in high elevation equatorial regions such as the high valleys and plateaus of Peru and Bolivia (approximately 4300 m elevation) and as such may be conditioned to higher levels of UV-B radiation. Although potato is not commercially grown at northern latitudes at 3000 m elevation it does well under wide diurnal temperature conditions. In the summer of 1976 reasonable yield for experimental purposes was obtained at 3200 m in Colorado. A potato leaf abnormality was noted at 2800 and 3200 m, possibly due to high irradiance levels. Wheat was chosen because it might also be UV-B resistant (Krizek, 1975) and because of its considerable importance as a major food crop.

The elevated site at approximately 3000 m above sea level was chosen for several reasons. Estimates by Becker and Boyd (1957) would indicate a 26% increase in insolation while Caldwell's (1968) work suggested an increase in global biologically effective UV-B irradiance of 2.5% to 12.6%, depending on the sun's zenith angle and air mass. Sauberer (Caldwell, 1968) would predict an increase of 34% UV-B irradiance of undetermined biological effectiveness. Tousey (1966) and Koller (1965) demonstrated the presence of the spectral lines 288.1 nm and 286.3 nm, respectively, at high elevations in the Alps. The anticipated high UV-B radiant flux density and shorter wavelength UV-B was seen as a natural way to simulate the effect of ozone depletion.

CONCLUSIONS

1. Solar UV-B irradiance at levels above those equivalent to a 20% reduction in stratospheric ozone reduced wheat plant stature.
2. Further investigation of solar UV-B by means of filtered lamps is needed prior to any future field experimentation.
3. Undue concern regarding detrimental effects on biomass resulting from 20% depletion of stratospheric ozone appear not warranted according to our investigation of wheat, potato, radish, and possibly pea.

RECOMMENDATIONS

1. Future research at high altitude should employ neutral density filtration of the UV-A and PAR regions.
2. The solar UV-B collector and irradiator concept should be investigated.
3. In any field studies, the UV-B, UV-A and PAR should be monitored continuously on classified days, so that true dosages may be ascertained.
4. The photographic technique of Tousey (1966) might be employed in high altitude studies so that evidence of <280 nm radiation might be gathered.
5. Photo-dosimetry should be investigated as a technique to determine dosages applied to whole plants. This technique would compensate for individual leaf positioning in relation to the UV-B source.

6. We suggest a workshop be held on solar UV-B manipulation techniques.

MATERIALS AND METHODS

Crop species and cultivars tested were: pea, *Pisum sativum* 'Alaska'; wheat, *Triticum aestivum* 'Inia 66'; potato, *Solanum tuberosum*, 'Kennebec'; and radish, *Raphanus sativus*, 'Cherry Belle'. All species were grown in steel containers of 2.4 liter (potato) and 1.2 liter capacity with drainage provided, Figure 1. An "artificial" medium was used TABLE 1.

The site chosen was at 3000 m elevation, 39^{o} 11' N latitude (BARC is 39^{o} 01' N latitude) and 106^{o} 56' W longitude located 43 km W of the Continental Divide and 11 km from the nearest highway. The surface was level and water and electrical power (110 v and 220 v) were available.

During the course of these studies all plants received 10 to 11 hours of direct sunlight per day. The site indicated in Figure 2 is mountainous and heavily forested, however, the site was chosen so that the horizon in all directions was not higher than 18^{o} from the horizontal plane.

Two studies were conducted. The first was an exclusion study involving both reduction and filtering of overall insolation including UV-B radiation. This approach takes advantage of the naturally high levels of UV-B radiation occurring at 3000 m elevation. The high levels of natural UV-B radiation were reduced using various filters. Thus, in this experiment the extra UV-B radiation was reduced with filters in such a way as to simulate stratospheric ozone depletion relative to sea level.

TABLE 1. GROWING MEDIUM PROPERTIES USED IN LAMP AND EXCLUSION STUDIES

1. 40% peat, 30% vermiculite, and 30% sand by volume.

2. Chemical properties.

pH	5.2
Texture	loamy sand
Organic matter	5.4%
Conductivity	2.5 mmhos/cm
NO_3-N	158 ppm
P	71 ppm
K	345 ppm
Fe	63.4 ppm
Zn	8.7 ppm
Cu	0.5 ppm
Mn	20.4 ppm

Nutrients added per liter of medium.

0.536 g $Ca(H_2PO_4)_2 \cdot H_2O$

0.357 g KNO_3

0.179 g $(NH_4)_2SO_4$

0.179 g slow release 14-14-14

0.005 g soluble trace element mix

inert	60.15%
Mn	8.15%
Fe	7.50%
Cu	3.20%
Zn	4.50%
B	1.45%
Mo	0.05%
S	15.00%

3. Water holding properties.

$\%H_2O$/DW	bars
100.0	0.0
49.2	- 0.1
24.0	- 0.3
21.0	- 0.5
18.0	- 1.0

Figure 1. Container - artificial medium culture of pea, wheat, potato, and radish used in the exclusion and lamp studies.

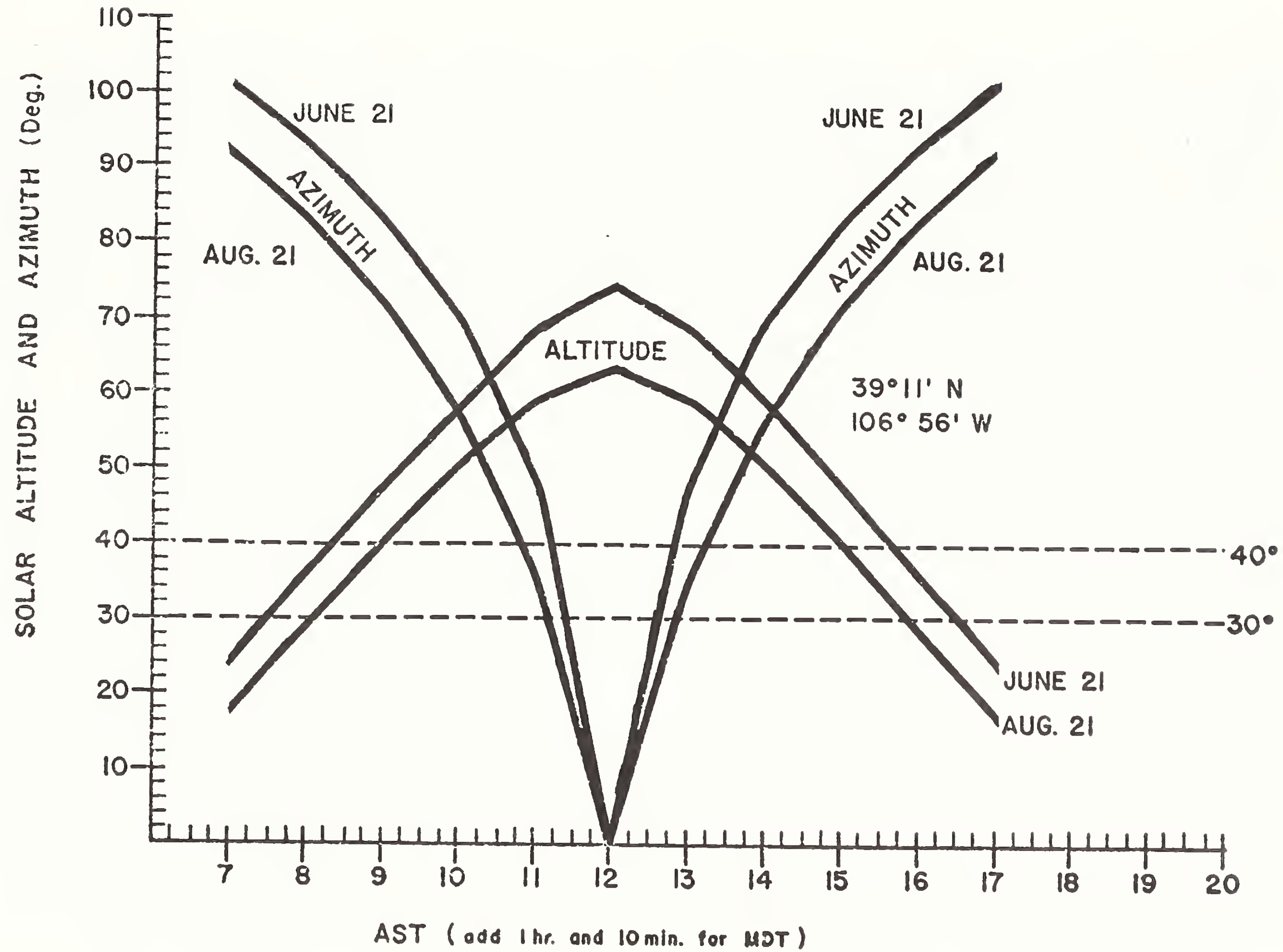

Figure 2. Graphic analysis of the sun position at the Colorado site during the exposure period, June 23 - August 13.

Treatments involved were: 1) an open control 2) a 26% insolation reduction using lath shading to simulate sea level insolation 3) cellulose acetate filtering to reduce UV-B radiation levels without substantial reduction in visible radiation 4) Mylar filtering to essentially eliminate UV-B radiation without substantial reduction in visible radiation and 5) Aclar filtering to reproduce the microclimate under the above filters without significant reduction of UV-B or visible radiation. The structures are illustrated in Figure 3. The transmission properties of Mylar and cellulose acetate are well understood and the transmission spectrum of Aclar is in Figure A-1 (Appendix). Aclar has no significant absorption above 230 nm through the visible region. Filter thicknesses were: cellulose acetate and Mylar, 5 mil; and Aclar, 1.5 mil. The experimental design employed was a randomized complete block with three replications per plant species. Treatment differences were tested by using the F test and if differences were significant, means were then separated using LSD procedures at the 5% level.

Spectral evaluation of the films *in situ*, as well as thermal analysis and total insolation measurements, were made with the BARC IRL Spec D spectroradiometer, an ISCO spectroradiometer, an Optronics radiometer, a Barnes IR thermometer, pyranographs, and a Leeds and Northrup recording potentiometer. Data are presented in Figure 4 and 5 and TABLE 2 and TABLE A-1 (appendix).

Figure 3. Exclusion study frames 91.5 x 213.5 cm, angle steel with adjustable steel pipe legs.

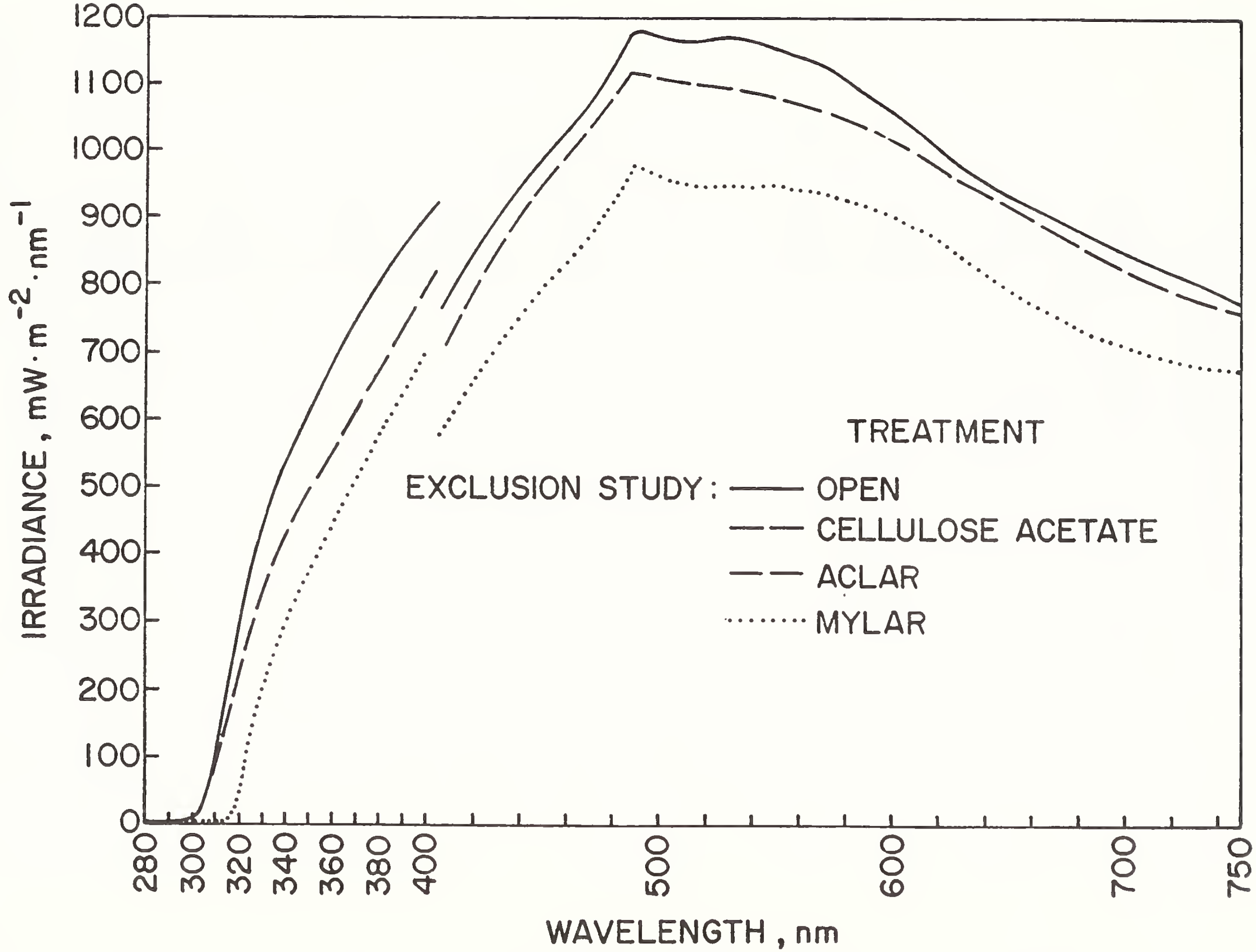

Figure 4. Sun spectra measured with the BARC Instrumentation Laboratory IRL Spec. D Spectroradiometer and an ISCO spectroradiometer.

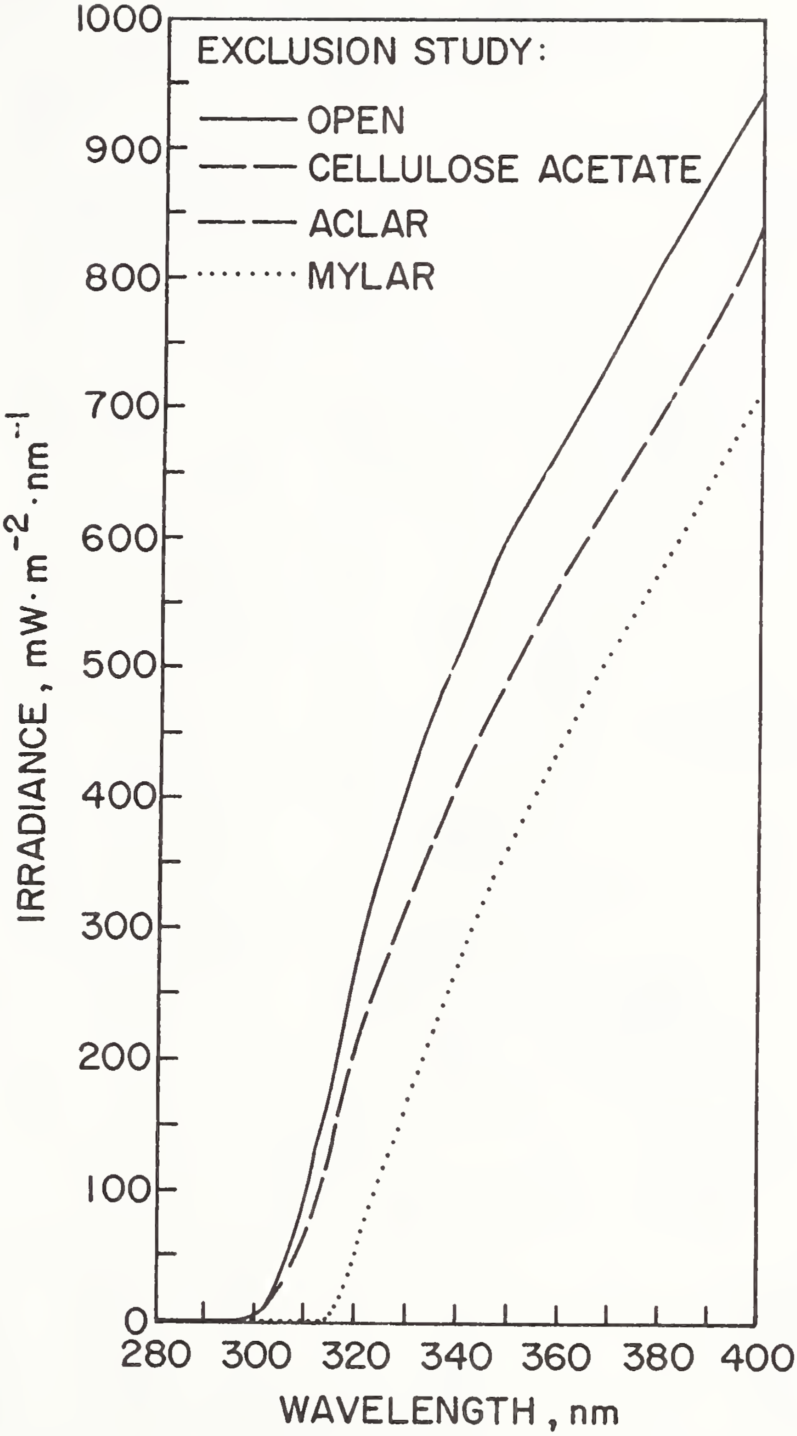

Figure 5. Sun spectra measured with the BARC Instrumentation Laboratory IRL Spec. D spectroradiometer.

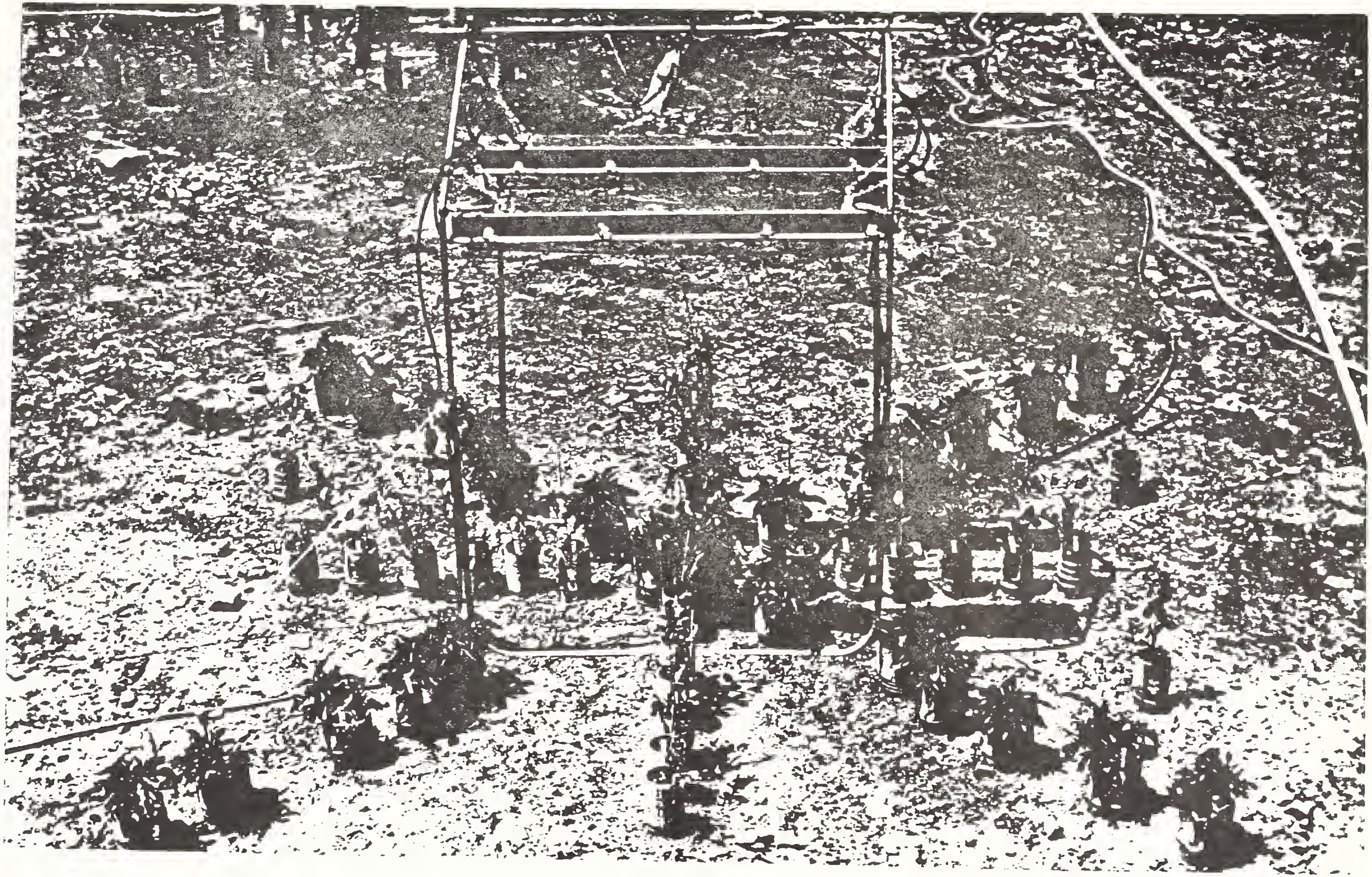

Figure 6. Lamp study conduit frames with a 96 x 127 cm structure suspending 2 fixtures, 4 FS40 sunlamps, 110 cm above plants.

TABLE 2. EXCLUSION STUDY, ENVIRONMENTAL PARAMETERS, POTATO

SOLAR FILTER	HOURLY MEAN TEMPERATURE (°C)			SOLAR RADIATION (W/m^2)
	AIR	PLANT	NATIVE SOIL	SOLAR NOON
NONE(OPEN)	12.9	12.7	16.2	803
Cellulose Acetate	(+0.7)[1]	(+1.4)	(+2.6)	(-63)
Aclar	(0.0)	(+1.5)	(+1.1)	(-21)
Mylar	(+0.2)	(+1.6)	(+2.7)	(-84)
Shade	(-0.2)	(0.0)	(-0.2)	(-208)

[1] Numbers in brackets indicate deviation from plants growing in the open.

The second study involved supplemental lighting in the field with Westinghouse FS40 sunlamps. The filtered sunlamps were operated for 6 hours each day (3 hours before and after solar noon) at a distance of 110 cm above the plants. Procedural protocol used with regard to lamps, lamp filters, lamp reflectors, lighting configuration, filter and lamp ageing, and filter changing was according to the instrumentation laboratory BARC. Figure 6 illustrates the basic four-lamp configuration employed. There were three treatments used. The first was lamps filtered with 5 mil cellulose acetate. Two control treatments were lamps filtered with Mylar which transmitted no UV-B radiation and reflectors without lamps to reproduce the microclimate of the lamp fixtures without adding radiation. Spectral evaluation of the filtered lamps *in situ* is presented in Figures 7 and 8. A split plot design was used in the lamp study with whole plots

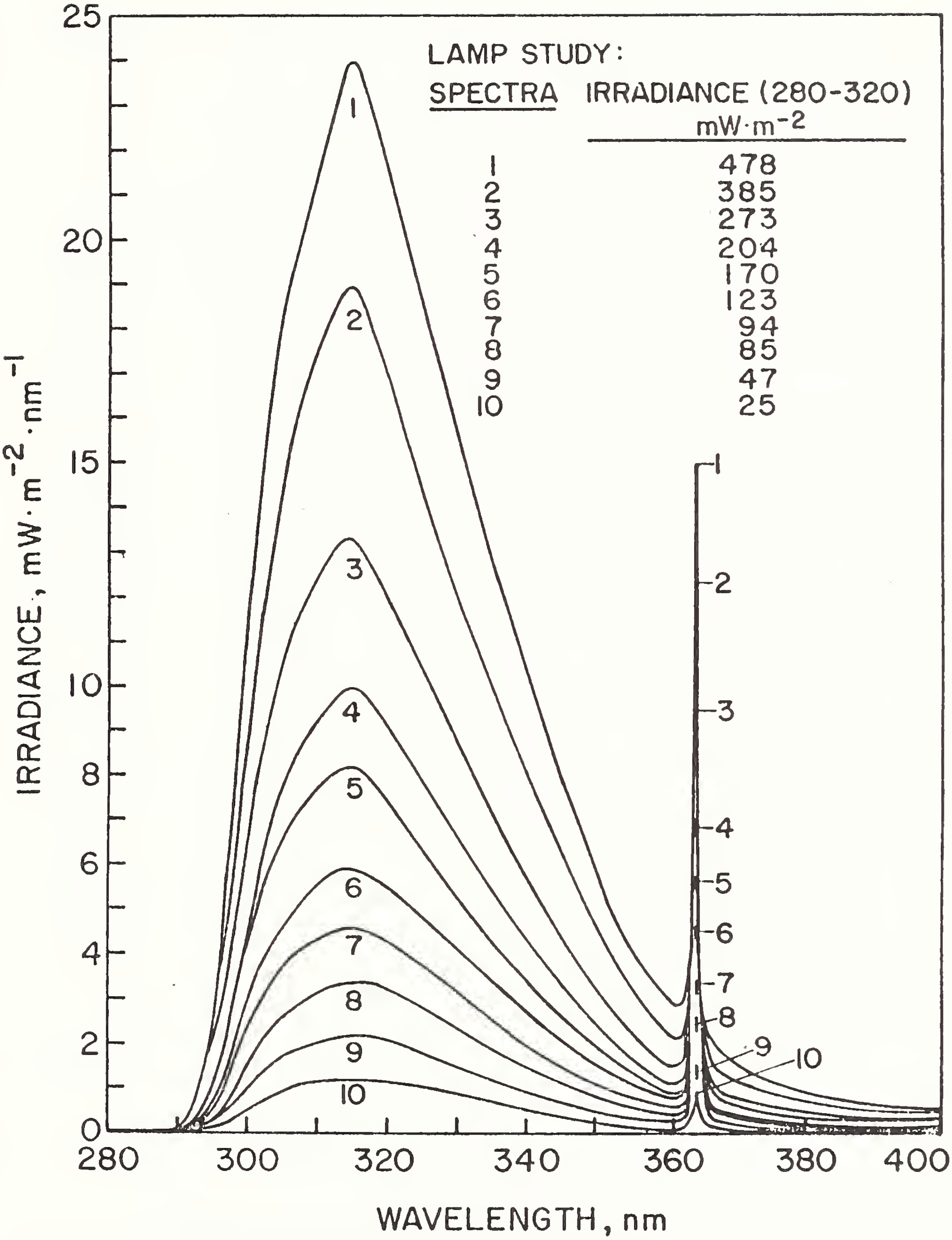

Figure 7. Cellulose acetate filtered FS40 lamp spectra and broad band summation measured with the BARC IRL Spec. D spectroradiometer at night.
Number 1 indicates a plant position directly under the center of the fixture. Number 10 indicates a plant position 212 cm from number 1 and in the same plane as number 1.

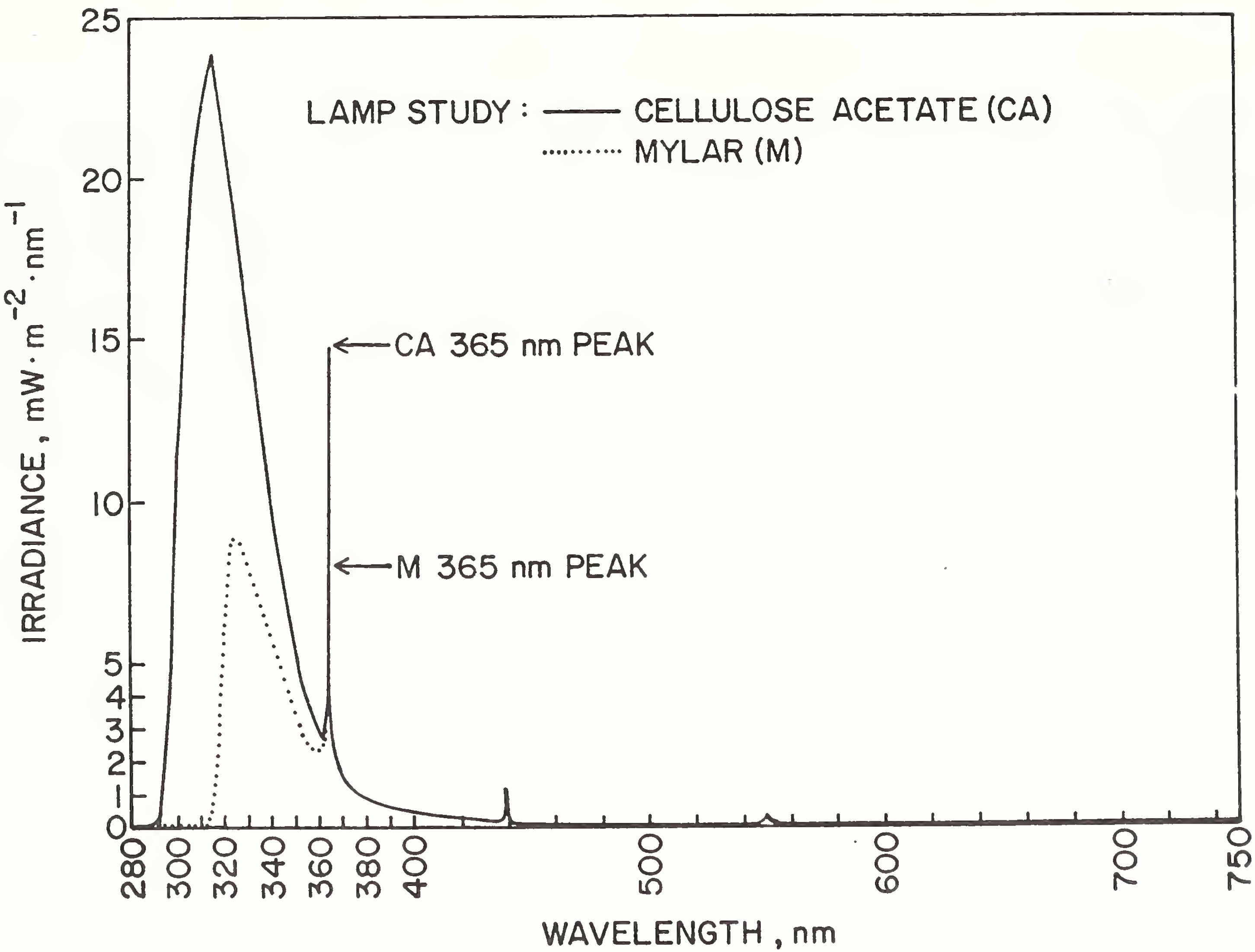

Figure 8. Comparison of cellulose acetate filtered and Mylar filtered FS40 lamp spectra. Measurements made with the BARC Instrumentation Laboratory IRL Spec. D spectroradiometer and ISCO spectroradiometer at night.

consisting of lamps filtered with cellulose acetate, lamps filtered with Mylar and lamp reflectors without lamps. Each plot was split into subplots of UV-B irradiance levels and/or position depending on the distance of the subplot from the lamps or reflectors. There were two replications of each of the three treatments for each of the four species. Regression analyses were performed on the interaction means when the interaction was found significant at the 5% level of probability.

Potato tubers were planted on June 6, wheat on June 18, radish and peas on June 29. Tuber "seed" consisted of whole potatoes each of which weighed 55 g $\pm$ 5 g. Containers were moved under lamp or exclusion structures just prior to emergence which occurred for all species during the last week of June and the first week in July. Duration of exposure and parameters measured are in the appendix. Over 15,000 individual plant measurements were made, including 71 parameters. The last plant observations were made on August 13. A diagram of the entire plot area is in Figure 9.

RESULTS AND DISCUSSION

Exclusion Study - The solar UV-B spectra of Beltsville (BARC) at 31 m elevation and the Colorado 3000 m site are compared in Figure 10. There was a marked increase in irradiance over the entire UV-B range in Colorado relative to Beltsville. These preliminary sepctra suggest that the Colorado site compared to the Beltsville site may have 2.7 times more biologically effective UV-B radiation. The weighted irradiance values were 8.3 and 3.1 mW/M^2 for Colorado and Beltsville, respectively. If these high UV-B

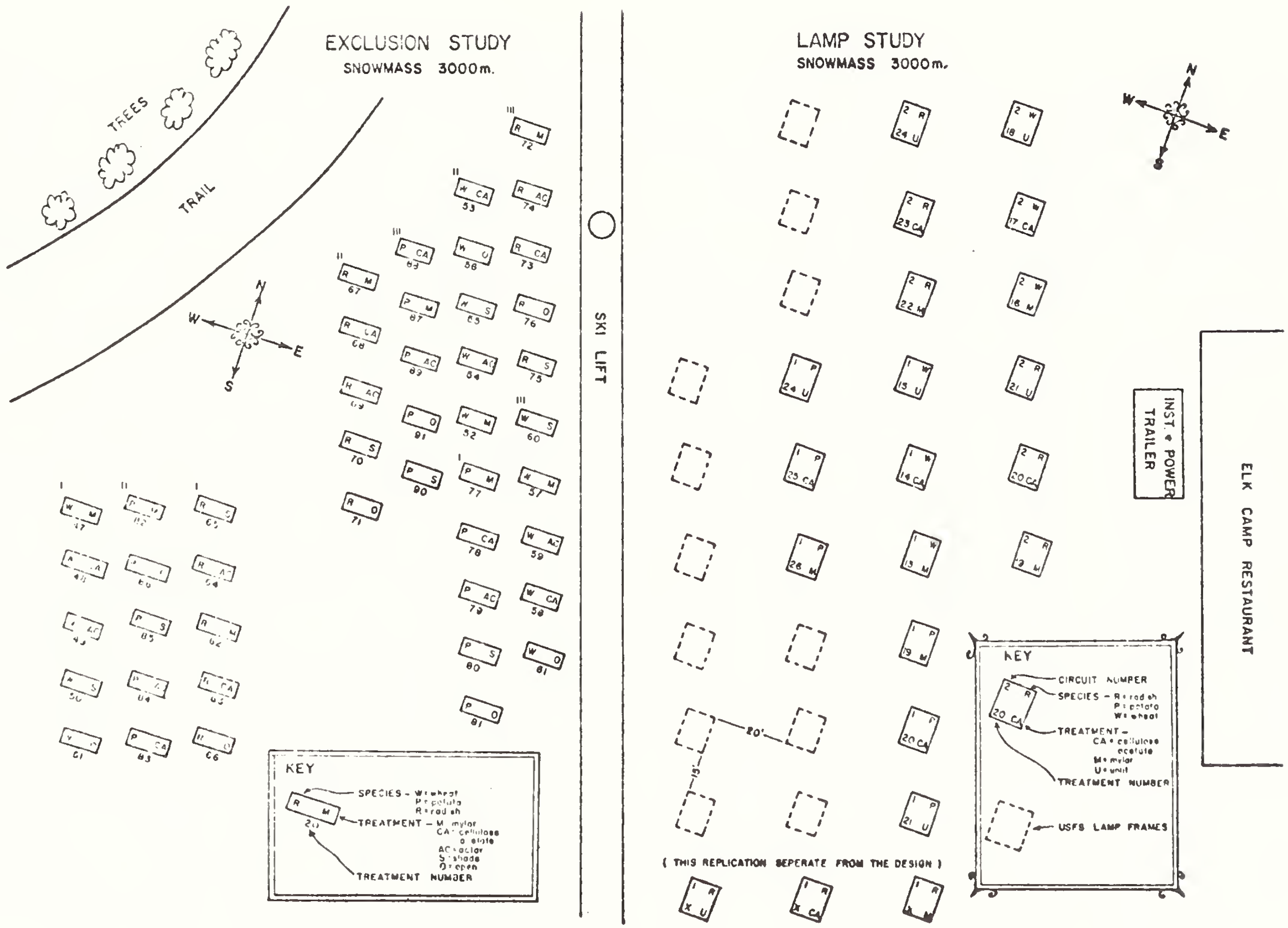

Figure 9. Experimental area depicting lamp and exclusion structure positioning at 3000 m elevation.

radiation levels can be verified in planned future study then exclusion experiments employing filters like cellulose acetate, Mylar and Aclar can easily be used to simulate 20% reductions in stratospheric ozone for low elevation regions.

In the exclusion study comparisons between cellulose acetate, Aclar and Mylar were made. In such an experiment effects which are to be attributed to UV-B radiation must be evident under cellulose acetate and Aclar filtration where natural UV-B radiation is present. Such UV-B radiation effects should not appear under Mylar filtration where no UV-B radiation was present. The only result showing a difference between the two types of filter treatments which could be attributed to UV-B radiation was wheat plant height indicated in Figure 11. All other measurements on wheat and other crops showed no significant difference attributable to UV-B radiation level. In general, sample homogeniety was good with little variability yet there was little detectable difference among the three filter treatments whether attributable to UV-B radiation or not (see appendix for more detail on other crops and parameters). Note that wheat, having increased UV-B radiation under cellulose acetate or Aclar, tended to be shorter in stature relative to the zero UV-B radiation control plants under Mylar. This effect was observed only in the wheat growth at 14 and 31 days. Mixed results not wholly attributable to UV-B radiation level were obtained after 50 days. Comparison of open and 26% shade treatments also showed a relative stunting of growth in the open for wheat. This effect was clear throughout the growth of the plants Figure 12.

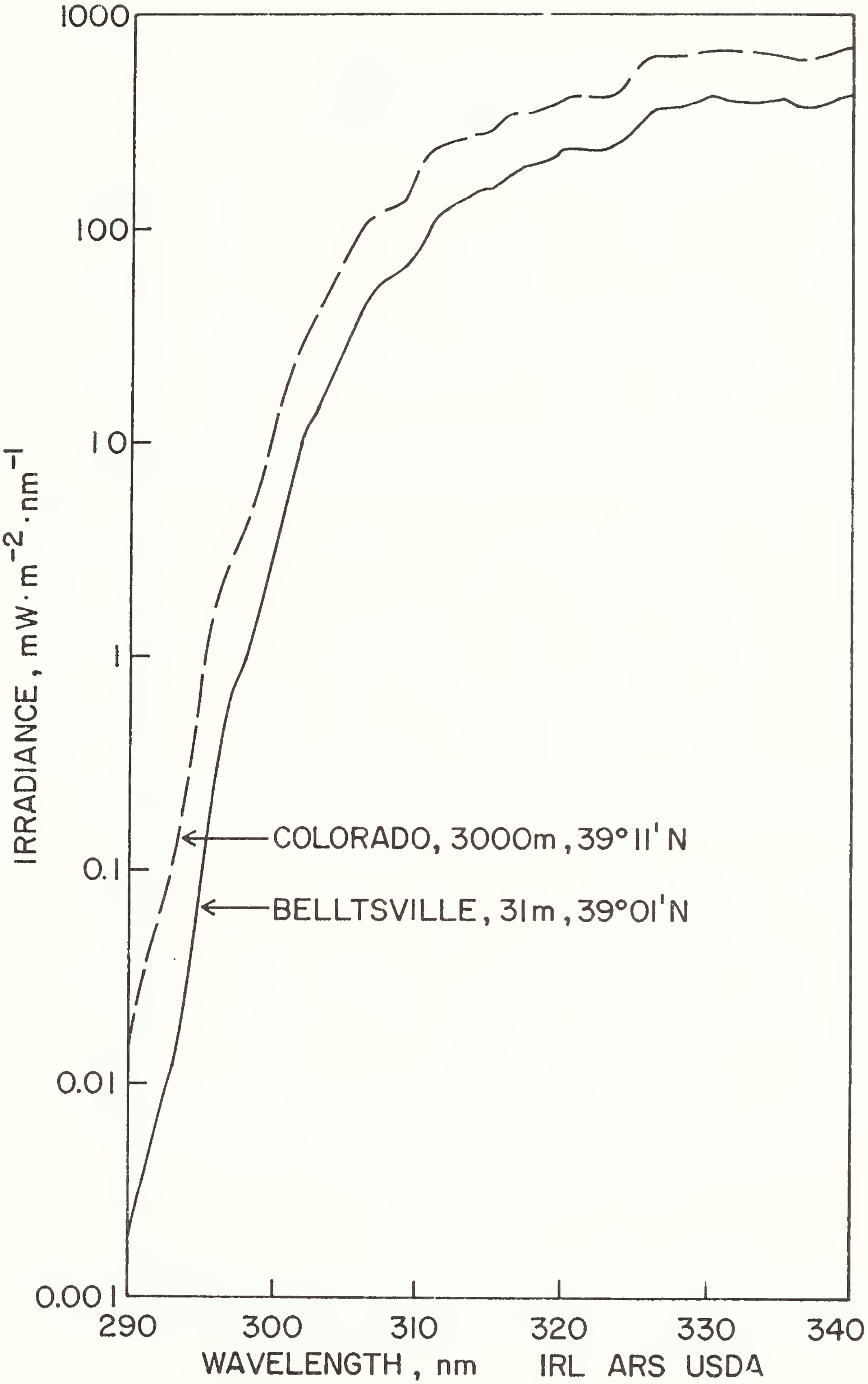

Figure 10. Comparison of solar UV-B spectra on two different "bright" days in August at Beltsville and the Colorado site measured with the same IRL Spec. D spectroradiometer.

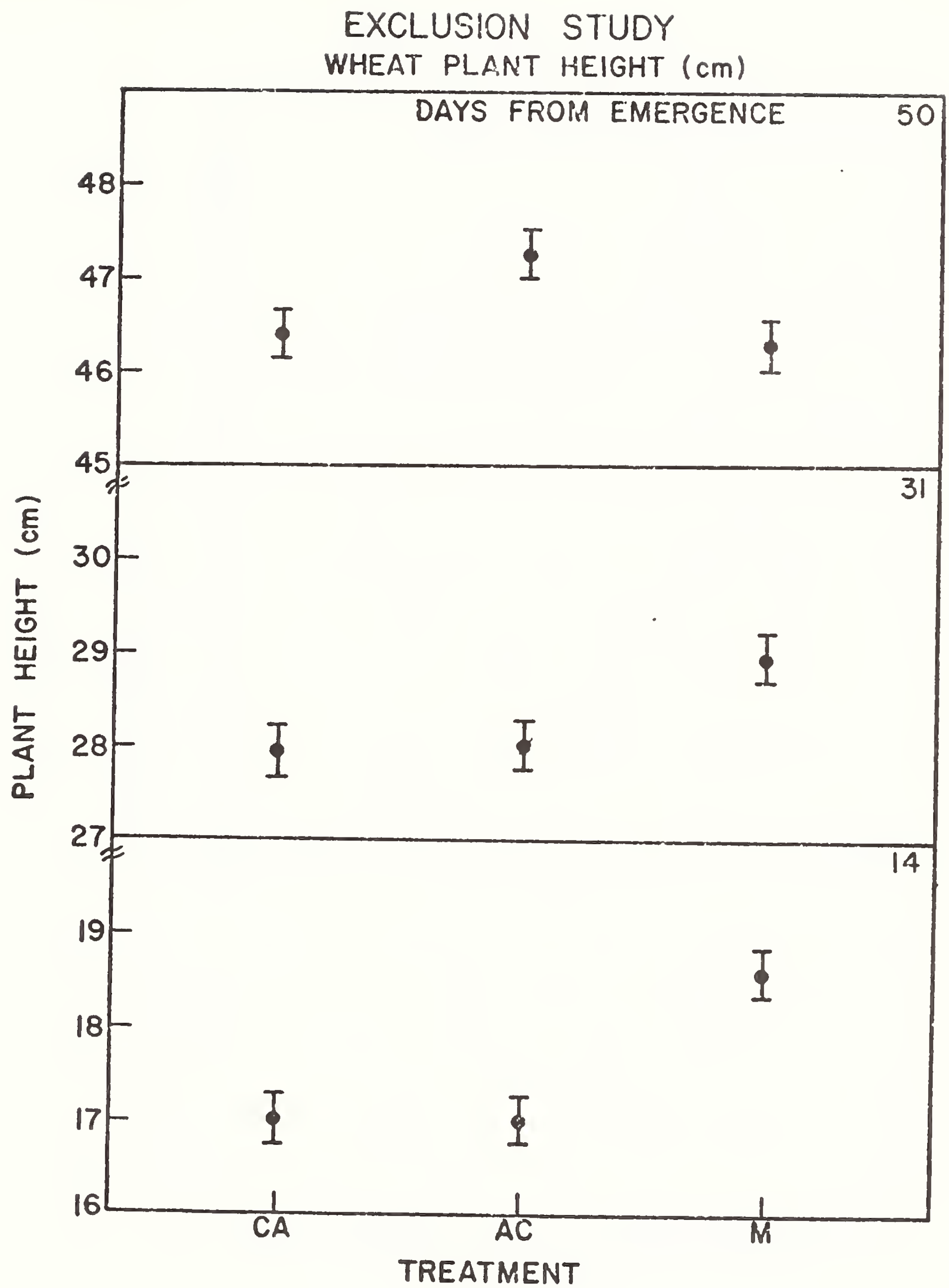

Figure 11. Wheat plant height as a function of UV-B exclusion (M = Mylar) and UV-B transmission (CA = cellulose acetate and AC = Aclar).

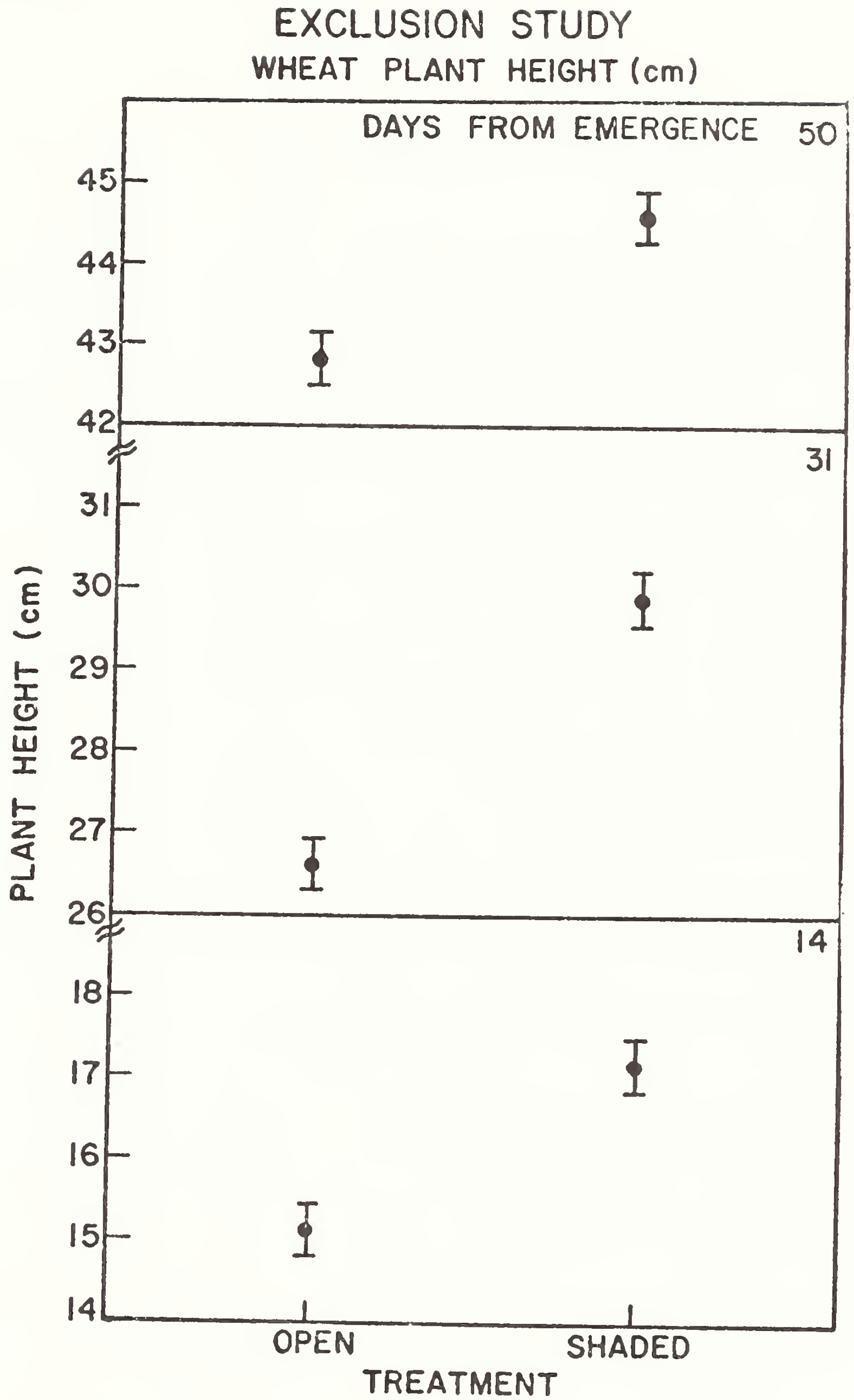

Figure 12. Wheat plant height in the open relative to 26% shade equivalent to sea level insolation.

However, again these results are unique to the wheat and were not obtained for the other species. Such results may be attributable to stunting effects of the extra UV-B radiation in the open; however, the differences are small. Of the many measurements made, no significant differences could be found with the other crop species.

A major confounding factor in exclusion studies such as these is caused by temperature differences under the different filters or shade treatments. Such temperature differences can cause plant changes which might be misinterpreted to be UV-B radiation effects. Therefore, careful temperature measurements were made and the summarized results are in TABLE 2 (more detailed results are in the appendix TABLE A-1). The average daytime temperatures of plants under 26% shade was slightly lower during the day but also slightly warmer at night. The average daytime temperatures of the plants under Aclar and cellulose acetate filtration (the UV-B radiation transmitters) were slightly lower than the plant temperatures under Mylar filtration. Otherwise the temperatures were generally similar. The total solar radiation levels under the three filter treatments, open and shade are in TABLE 2. Note that under the filter treatments the total radiation level is between 90 and 100% of the open control. Aclar is the best transmitter. Note also that these filters must be effective transmitters of the long wavelength radiation which normally accounts for 50% of the total solar radiation. The solar spectra under the three filters are Figures 4 and 5. They indicate that the UV-B transmission of cellulose acetate and Aclar is essentially the same from 280 to 750 nm

and that the Mylar cuts out the UV-B and reduces the visible radiation to some extent.

Lamp study - As a general statement there was very little or no response of plants growing under lamps generating UV-B radiation. Certain sets of data are selected to illustrate this lack of response in the wheat lamp study (Figures 13 and 14). Note for example, at 204 mW/m^2 (unweighted between 280 and 320 nm) in Figures 13 and 14 there was no difference in wheat foliage dry weight or plant height throughout the observation period. For potato foliage dry weight there was no dependence on UV-B radiation level (Figure 15). In fact, the only effect observed was with the no lamp control treatment which showed less dry weight production under the positions that would have had higher irradiation of lamps had they been present! Other examples of no or small effects can be found in the appendix tables (note particularly TABLES WL-2 and PL-5). In any case the effect is small. The only visible symptoms of UV-B radiation injury were observed for radish when the cellulose acetate filters were removed from the lamps and the plants were irradiated with strong 254 nm radiation. In such radish plants cotyledon folding was observed soon after emergence.

The above results lead one to suspect that our lamps did not give enough UV-B irradiation to constitute a 40% enhancement of UV-B radiation. A number of studies were conducted to check this point. Figure 7 shows the lamp irradiance with cellulose acetate filtration at various plant positions under the lamps. The results shows that a gradation of irradiance (including UV-B radiation) was present and the radiation level

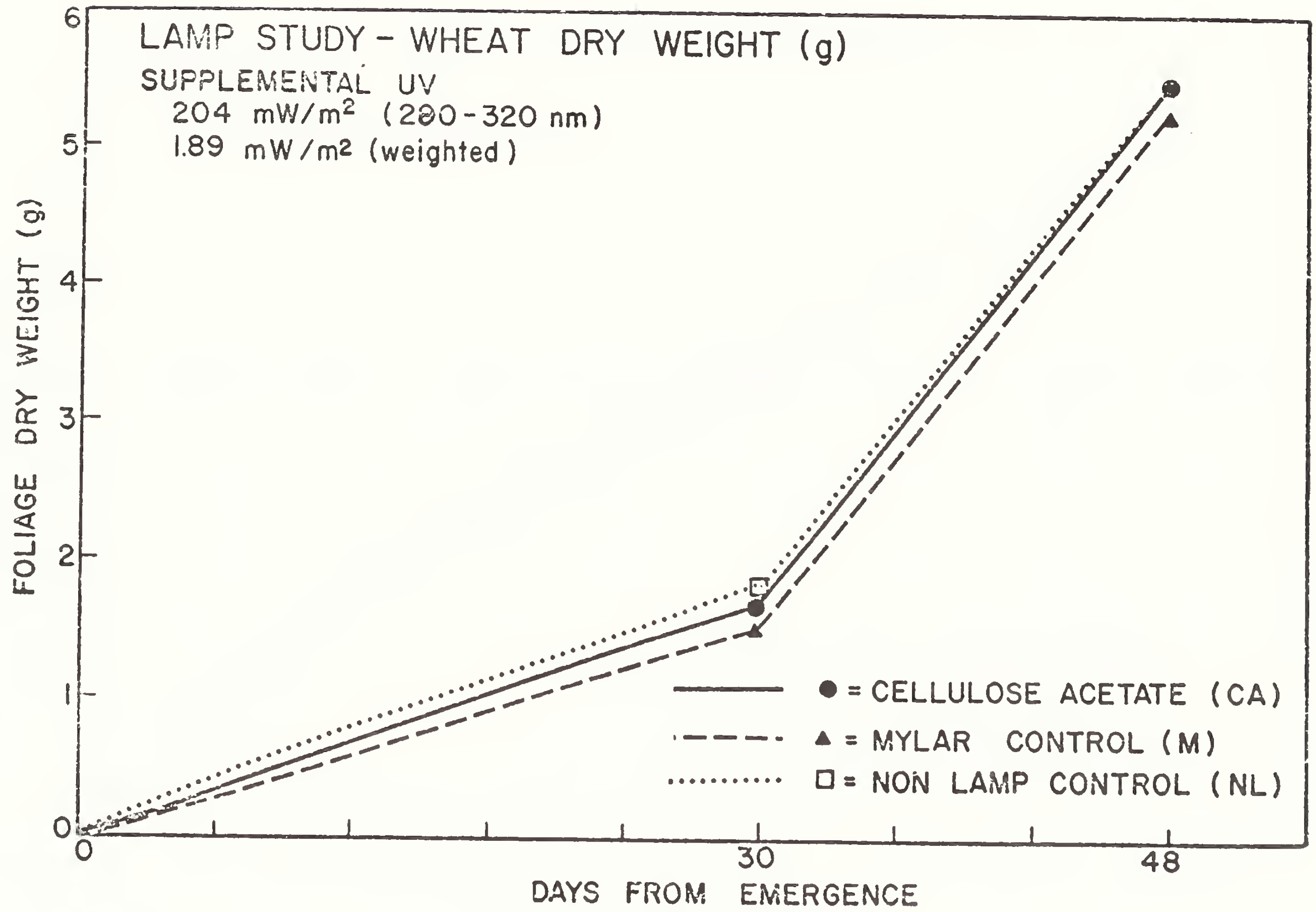

Figure 13. Comparison of the three lamp treatment responses with broad band UV-B irradiance held constant. Dry weights are the sum of the two plants.

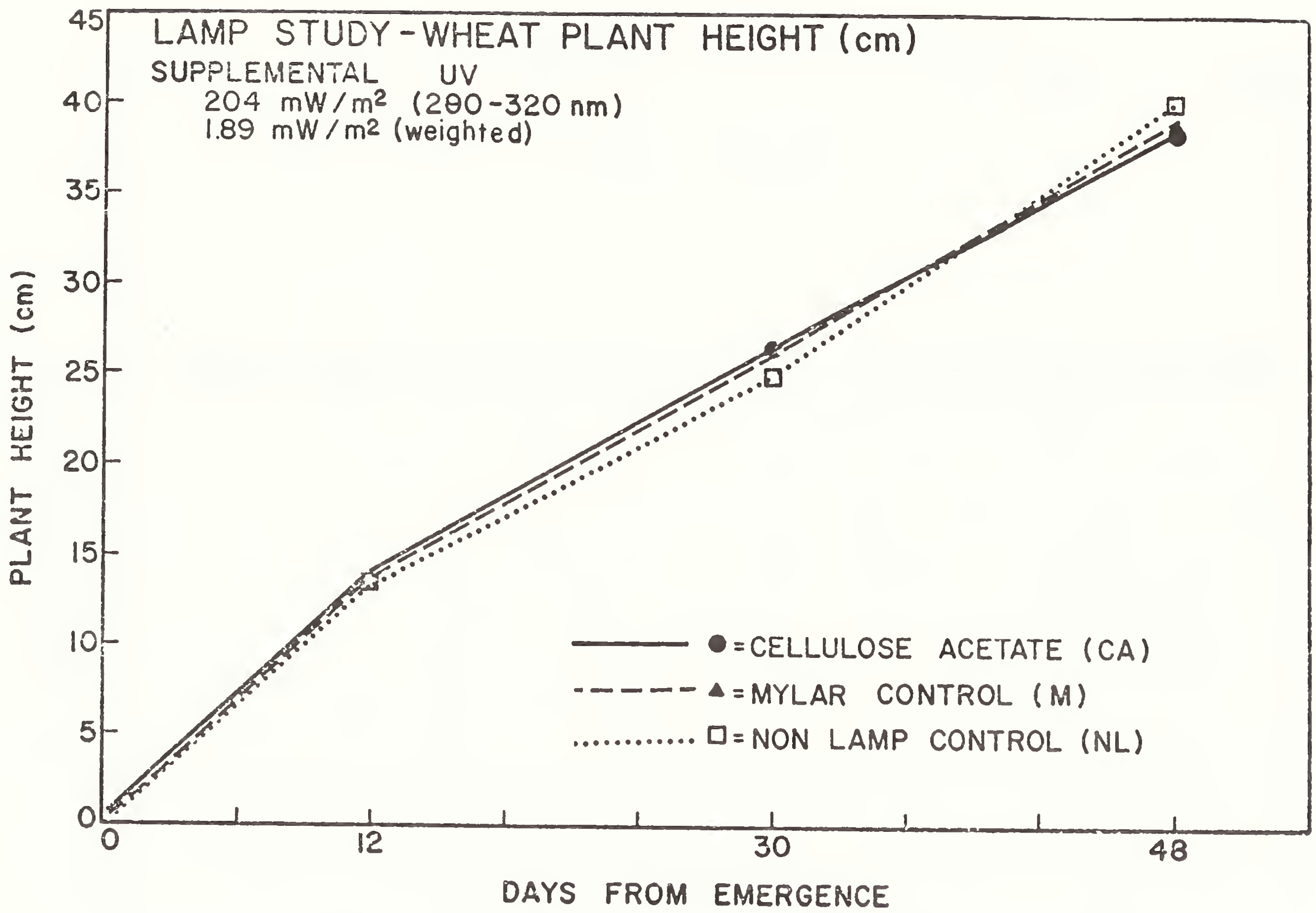

Figure 14. Comparison of the three lamp treatments responses with broad band UV-B irradiance held constant.

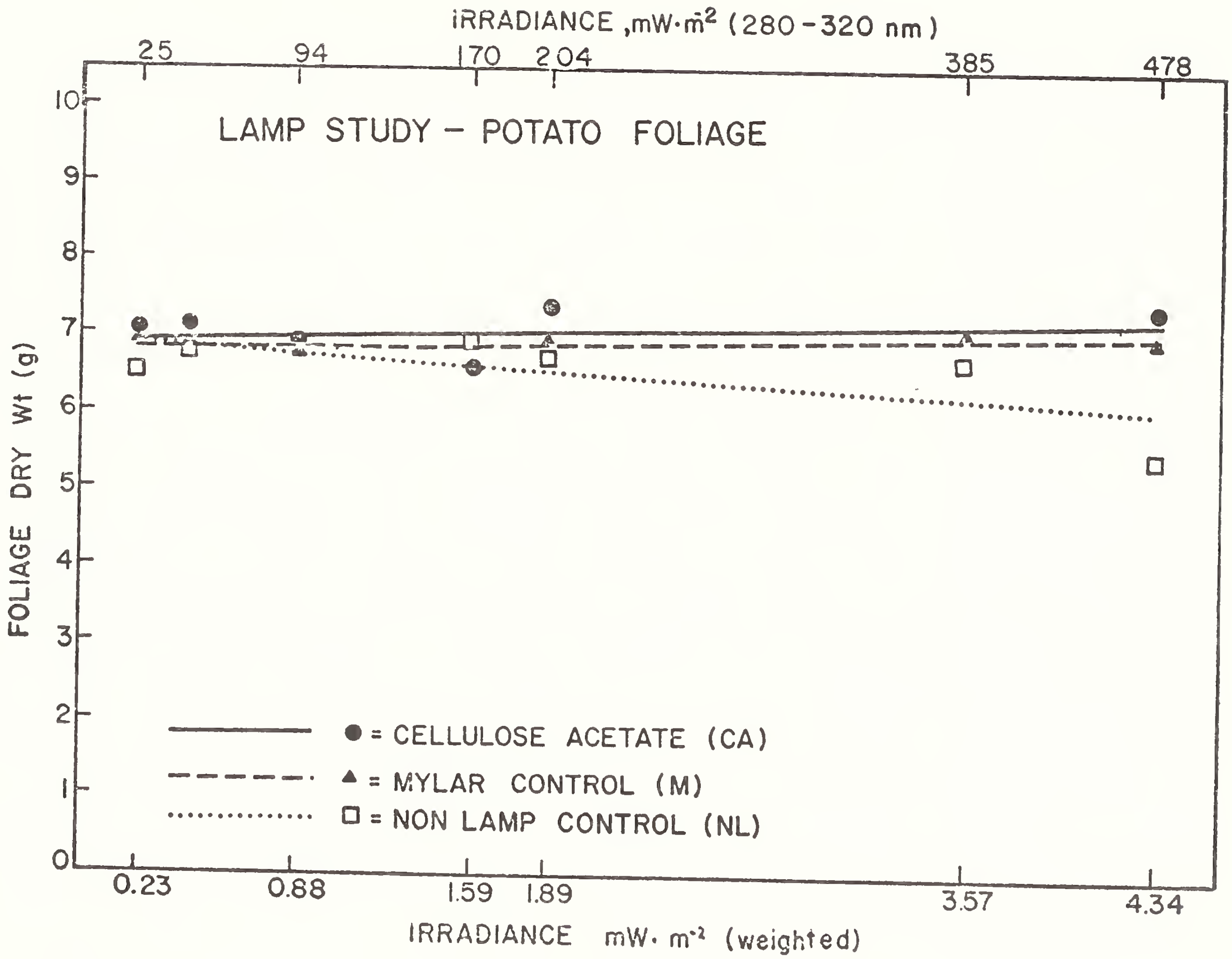

Figure 15. Comparison of interaction means fitted to linear models, 294 hrs lamp exposure during 49 days.

decreased with increasing diagonal distance from the lamps. The irradiation magnitude observed is also the expected magnitude to cause at least a 40% UV-B radiation enhancement (more probably a 160% enhancement directly under the lamps). In Figure 8 the cellulose acetate and Mylar filtered FS40 lamp spectra are presented for the highest plant irradiation position under the lamps. Note the general absence of radiation in the UV-A-PAR region (320-700 nm). Based on this it seems unlikely the lamps should induce additional photoreactivation etc. in the irradiated plants. However, compare the Colorado solar (natural) UV-B spectrum with the lamp spectra, i.e. compare Figure 5 with Figure 7. Such preliminary data suggests that the UV-B irradiance from the sun is overwhelming. Considerably more study at high elevation will have to be conducted.

There was an additional complicating factor in these lamp studies. Regardless of treatment there was a growth effect that could be detected under the lamp fixtures which was probably caused by the fixture microclimate. For example in wheat it was evident after the first set of observations taken 14 days after emergence that plant height was a function of position under the lamp fixtures Figure 16 . Figure 16 presents regression lines as a result of least squares fit to a "power" model. The power model accounted for 71%, 16%, and 60% of the variability in wheat height with regard to "unlit" (non-lamp), cellulose acetate, and Mylar filtered lamps, respectively. A linear model gave a somewhat higher R^2 for the UV-B transmitter, cellulose acetate. However, in either case the relationship between plant height and diagonal distance was negative

(inverse) while plant height and UV-B irradiance was positive, i.e. better growth in the positions subject to higher UV-B radiation. In any case, the effect illustrated in Figure 16 is very small. Since this occurred under all three treatments, the effect might be due to the protection of the centrally located plants from the primary UV-B source, the sun.

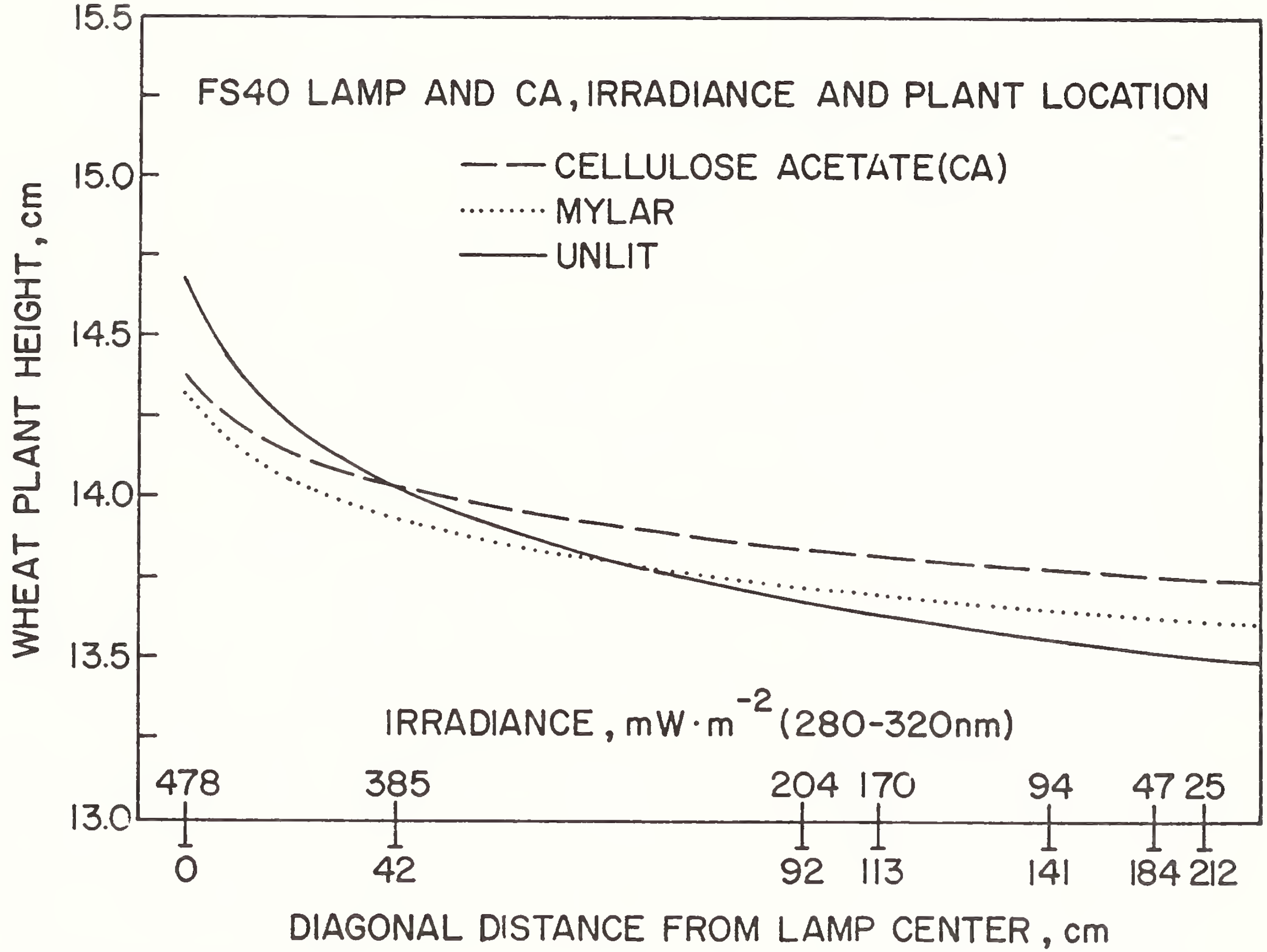

Figure 16. Wheat plant height as a function of diagonal distance from center of lamp fixtures (plant plane) and irradiance. Measurements made with the IRL Spec. D, spectroradiometer at night.

Of the 71 parameters evaluated in our two field studies including over 15,000 measurements on four crop species, only suppression of wheat vertical growth in exclusion studies could be considered a real response to solar UV-B irradiance level that corresponds to a stratospheric ozone depletion of 20%. Economic concern based on this study seems unwarranted. Indeed "short stem" wheat is popular and has constituted part of the "green revolution" popular in some areas of the globe.

The lamp study was carried out using a similar field procedure to that described by Sisson and Caldwell (1975) in that solar irradiance was supplemented when the solar altitude exceeded 40^{o}; Figure 2. During this period the sun would contribute greater than 80% of each days's UV-B irradiance (Caldwell, 1968). As it happened no clear cut response was noted in this study. Explanations might include the fact that biologically effective solar UV-B was overwhelming (Figure 2) relative to biologically effective lamp UV-B. Another explanation is that some microclimate (such as shading) under the lamp fixtures protected the plants and counteracted the adverse effect of UV-B radiation. Also the high UV-A-PAR radiation typical of this high elevation site may have contributed to strong photoreactivation or provided other means of repair of UV-B radiation damage. Another factor possibly having some bearing on the outcome of the lamp study may be the fact that the 4 crop species employed are considered cool season species and may be in some way resistant to UV-B injury. Cotton a decidedly warm season crop appears sensitive to UV-B injury at least in the seedling stage of

growth (Krizek 1975, Carns and Christiansen 1975).

No visual evidence such as lesions (Caldwell, 1968), browning (Moore, 1971), red pigmentation, glazing or leaf curviture (Caldwell, 1971) was noted with regard to any of the four species studied in this test. Particular attention was paid to the center lamp position (4.34 $mW.m^{-2}$) lamp contribution at 280-320 nm and the open treatment (8.28 $mW.m^{-2}$) at 280-320 nm. The preceeding are weighted values related to UV-B Beltsville Sun Equivalents.

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APPENDIX

Various experiments were conducted which were preliminary or provide additional technical information. Such results are collected here without detailed analysis. Results collected include:

1) The spectrum of Aclar (Figure A1)

2) The UV-B radiation output from FS40 lamps filtered with cellulose acetate as a function of time energized and lamp temperature (Figure A-2 and A-3).

3) A potential solar UV-B collector and irradiator which could be used to enhance solar UV-B radiation without the use of filtered lamps (Figure A-4).

4) Detailed temperature analysis for plants in exclusion study (TABLE A-1).

5) Preliminary results for wheat leaf viability tests for UV-B irradiated leaves. The test involved the use of elctrolyte leakage as a measure of leaf tissue cell lysis (TABLE A-2).

6) Tabulated technical data for exclusion studies on wheat, potato, and radish (TABLES WE-1; PE-1; RE-1).

7) Tabulated technical data for various FS40 lamp irradiations on wheat (TABLES WL-1 to WL-5), potato (TABLES PL-1 to PL-6), radish (TABLES RL-1 to RL-6), and pea (TABLES PEL-1 to PEL-3).

Information developed during our studies would indicate that perhaps cellulose acetate should be solarized 8 hours prior to use as FS40 lamp filters. Since lamp output begins to decline at 6^{o} C ambient temperature,

the mountain researcher should measure UV-B irradiance *in situ* at the beginning and end of the illumination period. Fortunately, in our lamp study, temperatures were above 6^{o} C at the beginning and end of the illumination period. Aclar appears to be a good "window" for use in exclusion studies, however, 1.5 mil film used in our studies does not have a comfortable safety margin with regard to tearing. Five mil material is suggested.

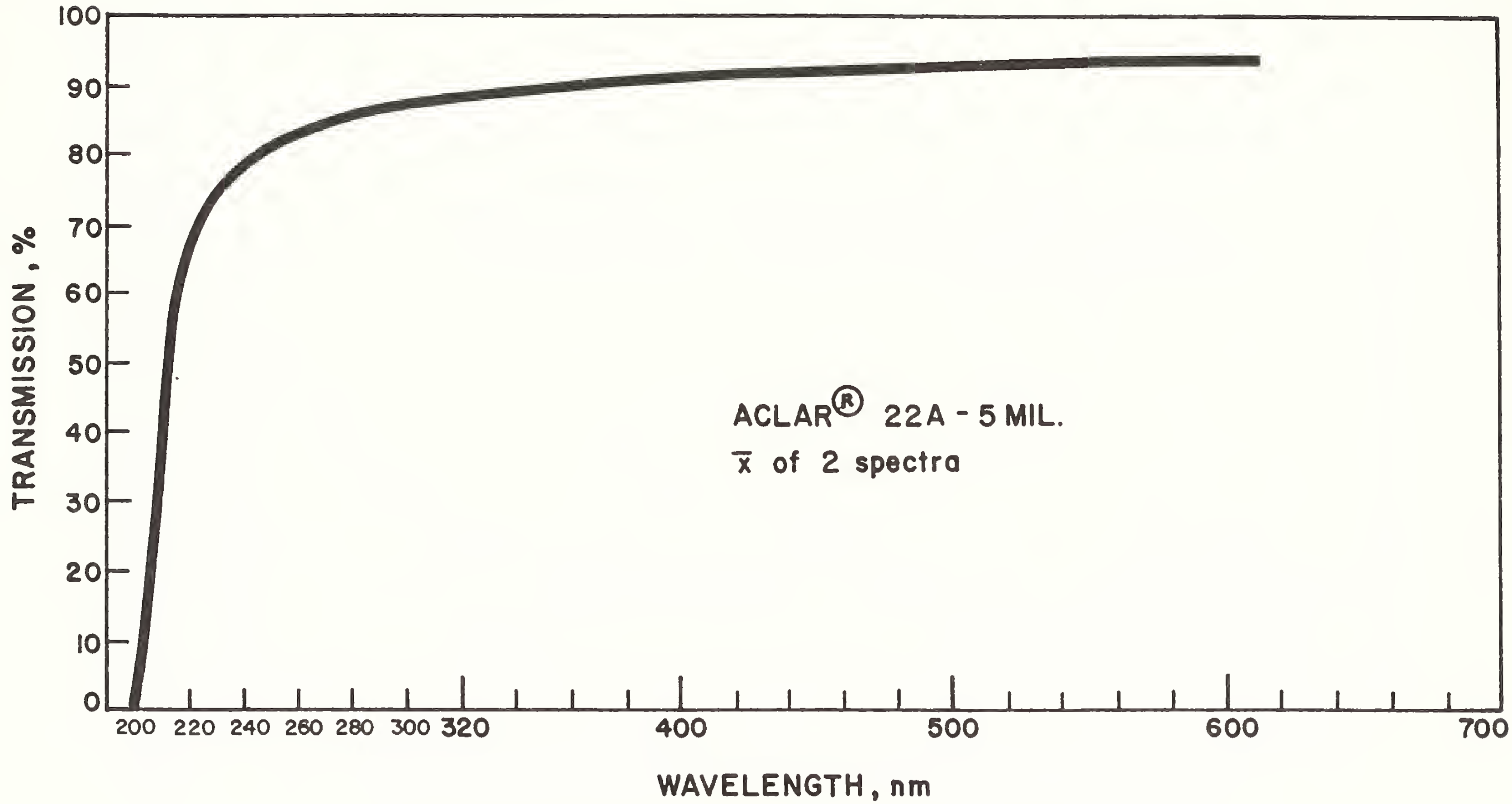


Figure A-1. Laboratory spectra developed with Perkin and Elmer spectrophotometer. Aclar is a flexible thermoplastic film manufactured by Allied Chemical Corporation from fluorinated-chlorinated resins.

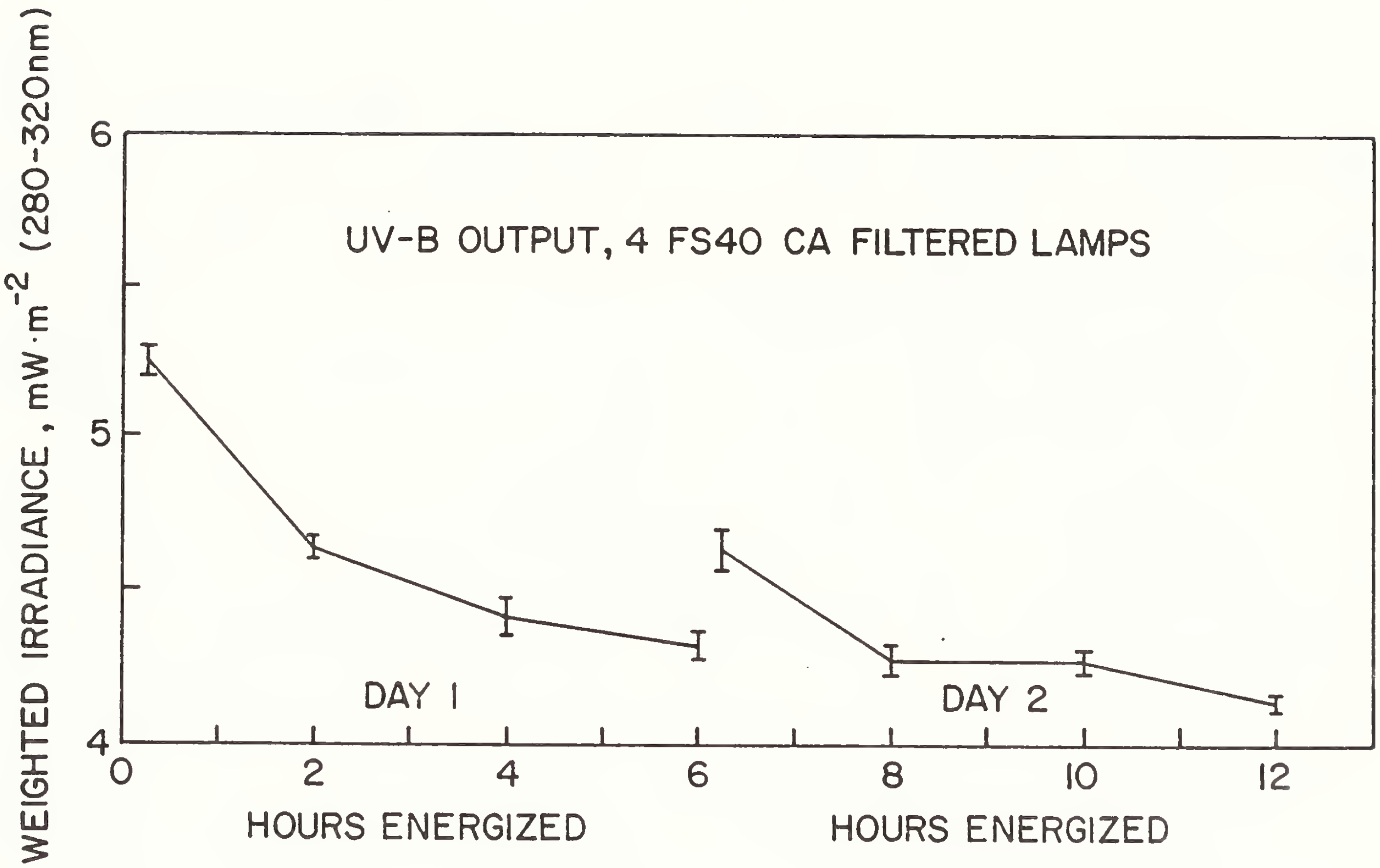
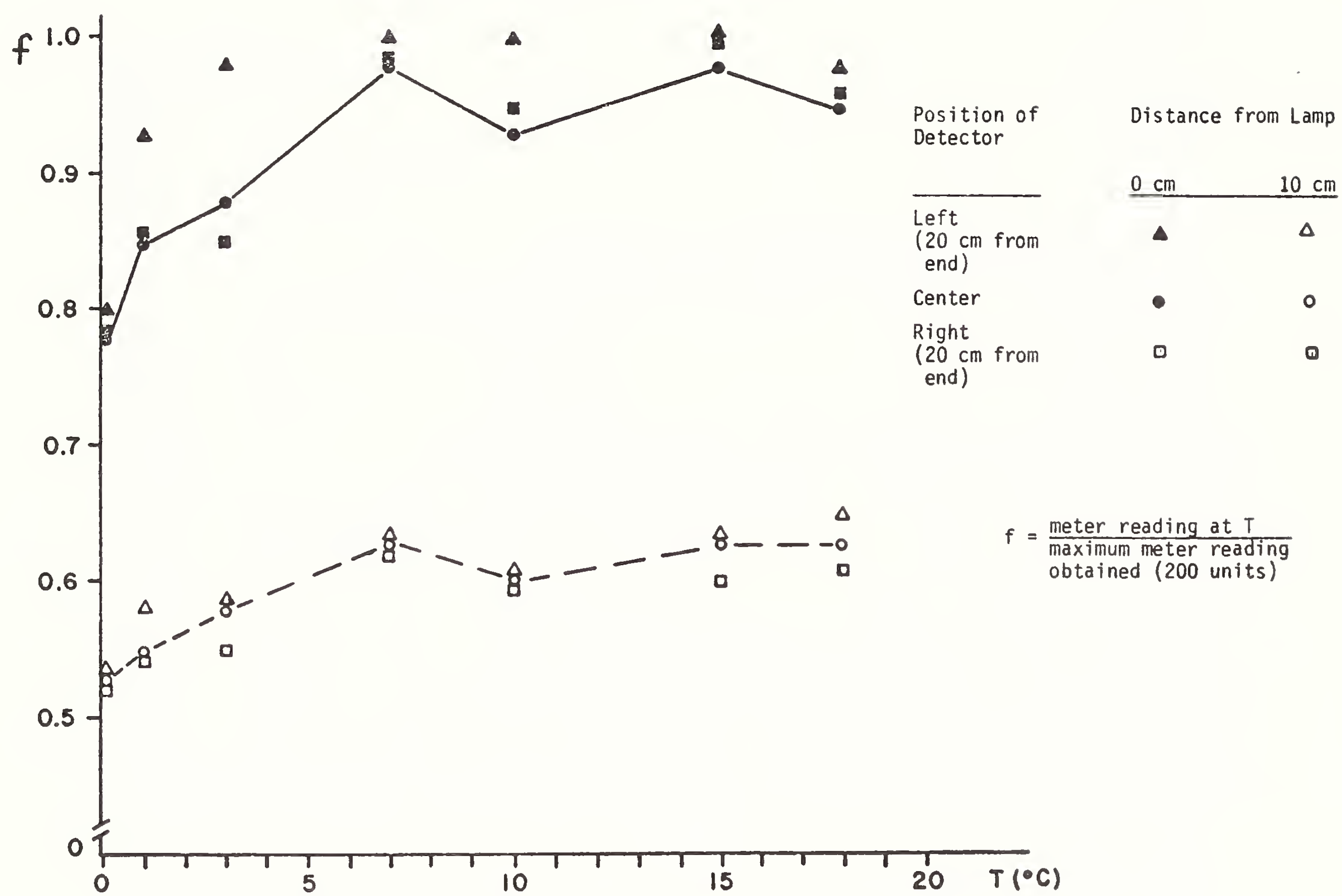


Figure A-2. Variability in broad band UV-B irradiance for 2, 6 hour periods including 7, 4-lamp sets. Prior to the test lamps were operated for 100 hrs. and cellulose acetate was solarized for 6 hrs.

Lamps were operated for approximately 200 hours prior to test.
A G.E. "214S ultraviolet meter" was used.



Relative Intensity Output, f, of FS40 Lamp as a Function of Temperature, T (^{o}C). A Reflector was not used. Only points for lamp center measurements are connected.

Figure A-3.

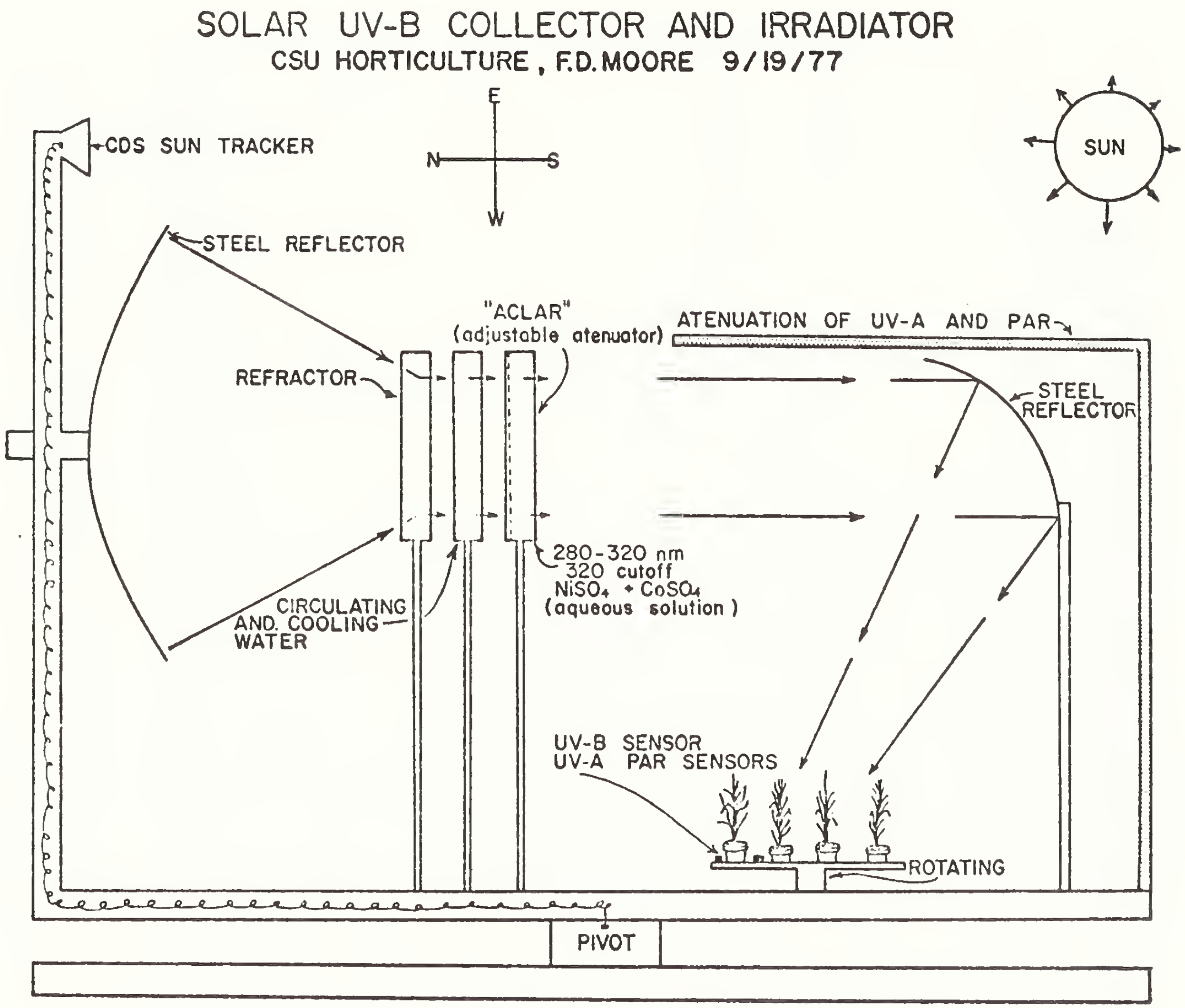


Figure A-4. Design of a potential solar UV-B research tool.

TABLE A-1. EXCLUSION STUDY: AIR, PLANT, AND NATIVE SOIL TEMPERATURES, POTATO[1]

Solar filter		24 hr mean temperatures (°C) air	plant	soil
	max	20.8	19.0	24.5
None (open)	mean	12.9	12.7	16.2
	min	5.5	7.0	8.0
	max	21.8	19.8	30.5
Cellulose acetate	mean	13.6	14.1	18.8
	min	6.0	8.5	10.5
	max	20.6 $\boxed{21.20}$[2]	21.5 $\boxed{20.65}$	28.0 $\boxed{29.25}$
Aclar	mean	12.9 $\boxed{13.25}$	14.2 $\boxed{14.15}$	17.3 $\boxed{18.05}$
	min	5.8 $\boxed{5.90}$	8.3 $\boxed{8.40}$	9.8 $\boxed{10.15}$
	max	21.3	21.5	29.5
Mylar	mean	13.1	14.3	18.9
	min	5.8	8.3	10.5
	max	21.1	18.0	24.5
Shade	mean	12.7	12.7	16.0
	min	5.4	7.5	9.0

[1] Temperatures were measured continuously for a period of one hour every third hour (8 times for each of two 24 hr periods). Precision is ± 0.4°C.

[2] Values in boxes are means of both UV-B transmitters to be compared with Mylar.

TABLE A-2. RELATIVE WHEAT LEAF ELECTROLYTE LEAKAGE [1,2]

Evaluation	Samples showing visual injury (% electrolytes leaked)	Samples appearing healthy (% electrolytes leaked)
1	29	56
2	17	13
3	57	12
4	32	37
5	27	13
6	31	21
mean	32	25

1. Results in the two columns were not significantly different at even the 10% level (unpaired t test).

2. Relative electrolyte leakage was $x = 7 \pm 1.5\%$ standard deviation.

TABLE WE-1. MEANS AND MEAN SQUARES FROM EXCLUSION EXPERIMENT, WHEAT

	FRESH WT	DRY WT	FRESH WT	DRY WT	PLANT HT	PLANT HT	PLANT HT	HEAD LENGTH	HEADS	TILLERS
Exposure (hrs, days)	186,31	186,31	300,50	300,50	84,14	186,31	300,50	300,50	300,50	300,50
Units	g	g	g	g	cm	cm	cm	cm	%	no/plant
Open	3.88a[1]	0.71	8.30	2.49	15.1c	26.6d	42.8d	1.7c	60.0b	2.4a
Shade	3.97a	0.67	8.30	2.39	17.2b	29.9a	44.6c	1.2c	45.2c	2.0c
CA	3.58b	0.79	8.26	2.46	17.0b	27.9c	46.4b	3.7a	78.0a	2.2b
AC	3.58b	0.66	8.28	2.42	17.0b	28.0c	47.3a	2.5b	71.2a	2.0bc
M (-UVB)	3.78ab	0.72	8.07	2.42	18.6a	28.9b	46.3b	3.9a	79.7a	2.0b
Treatment										
MS	2.98**	0.008	0.472	0.004	73.1**	210.5**	304.3**	138.91**	19766.1**	2.185**
df	4	4	4	4	4	4	4	4	4	4
Error										
MS	0.81	0.011	1.895	0.021	1.8	7.5	8.2	3.59	942	0.271
df	465	8	225	8	225	705	465	465	465	465
Total observation	480	15	240	15	240	720	480	480	480	480
Observations/$\bar{x}$	96	3	48	3	48	144	96	96	96	96

[1] Column means separated by LSD, 5% level. Means followed by the same letter are not significantly different

TABLE PE-1. MEANS AND MEAN SQUARES FROM EXCLUSION EXPERIMENT, POTATO

	FOLIAGE FW g	FOLIAGE DW g	TUBER FW g	TUBER DW g	FW/TUBER g	DW/TUBER g	FOL FW/ TUB FW	FOL DW/ TUB DW	TUBER NO	STEM NO	TUBERS/ STEM
Open	67.81c[1]	7.35	29.54	14.21	14.21	2.76	0.45b	0.25	11.7	8.8	1.5
Shade	80.73a	7.79	28.18	14.30	14.30	2.70	0.54a	0.28	11.3	8.3	1.4
CA	71.59bc	7.72	29.05	12.12	12.12	2.41	0.49ab	0.27	12.7	8.6	1.5
AC	73.70abc	7.62	28.44	13.98	13.98	2.59	0.51a	0.27	11.2	8.8	1.4
M(-UVB)	76.22ab	7.93	28.21	14.52	14.52	2.83	0.53a	0.28	11.3	9.1	1.3
Treatment											
MS	354.00*	0.7192	188.84	5.309	14.17	0.3921	0.0206**	0.0029	5.626	1.113	0.1821
df	4	4	4	4	4	4	4	4	4	4	4
Error											
MS	118.79	0.8441	123.04	5.746	20.51	0.7444	0.0048	0.0012	11.679	6.993	0.3071
df	60	60	60	60	60	60	60	60	60	60	60
Total observations	75	75	75	75	75	75	75	75	75	75	75
Observations/ $\bar{x}$	15	15	15	15	15	15	15	15	15	15	15

[1]Column means separated by LSD, 5% level. Means followed by the same letter are not significantly different.

TABLE RE-1. MEANS AND MEAN SQUARES FROM EXCLUSION EXPERIMENT, RADISH.

	FOLIAGE FW	FOLIAGE DW	FOLIAGE FW	FOLIAGE DW	ROOT FW	ROOT DW	ROOT FW	ROOT DW	FOLIAGE FW/ROOT FW	FOLIAGE DW/ROOT DW	FOLIAGE FW/ROOT FW	FOLIAGE DW/ROOT DW
Exposure (hrs., days)	144,24	144,24	216,36	216,36	144,24	144,24	216,36	216,36	144,24	144,24	216,36	216,36
Units	g	g	g	g	g	g	g	g	g	g	g	g
Open	2.80a[1]	0.35	4.66b	0.62b	4.34a	0.29	11.52b	0.76b	1.72	1.22	0.46	0.83
Shade	2.47b	0.28	4.20b	0.54b	3.04b	0.19	9.18c	0.62c	1.11	1.50	0.50	0.88
CA	2.71ab	0.33	5.60a	0.79a	3.88a	0.25	14.83a	0.95a	0.76	1.33	0.43	0.84
AC	2.61ab	0.31	5.39a	0.76a	3.83a	0.23	14.21a	0.90ab	0.77	1.48	0.40	0.84
M(-UVB)	2.86a	0.35	5.44a	0.73a	4.40a	0.29	13.20ab	0.89ab	0.93	1.22	0.44	0.83
Treatment												
MS	0.9881*	0.0026	15.17**	0.0341**	12.48**	0.0056	218.6**	0.0537**	6.66	0.0573	0.055	0.0016
df	4	4	4	4	4	4	4	4	4	4	4	4
Error												
MS	0.3884	0.0009	1.7357	0.0034	2.168	0.0018	19.8	0.0060	7.57	0.0361	0.025	0.0085
df	195	8	195	8	195	8	195	8	195	8	195	8
Total observa-tions	210	15	210	15	210	15	210	15	210	15	210	15
Observa-tions/$\bar{x}$	42	3	42	3	42	3	42	3	42	3	42	3

[1]Column means separated by LSD, 5% level. Means followed by the same letter are not significantly different.

TABLE WL-1. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT WHEAT FOLIAGE, WT, LAMP EXPOSURE 192 HRS DURING 32 DAYS

UVB LAMP IRRADIANCE		FRESH WT			DRY WT		
		+UVB	-UVB		+UVB	-UVB	
Weighted	Non-weighted	CA	M	U	CA	M	U
$mW.m^{-2}$	$mW.m^{-2}$	g	g	g	g	g	g
4.34	478	4.2	3.7	4.2	0.91	0.76	0.92
3.57	385	3.8	4.0	4.0	0.82	0.85	0.85
2.52	273	4.2	3.8	4.4	0.85	0.78	0.93
1.89	204	4.0	4.0	3.8	0.84	0.81	0.83
1.59	170	3.8	3.8	4.1	0.82	0.80	0.88
1.12	123	3.8	4.2	4.4	0.84	0.87	0.96
0.88	94	3.9	4.0	4.1	0.82	0.82	0.80
0.65	85	3.6	3.6	3.5	0.77	0.75	0.76
0.44	47	4.1	3.9	3.7	0.89	0.82	0.81
0.23	25	4.2	4.1	3.7	0.90	0.86	0.81
$\pm$UVB means		4.0	3.9	4.0	0.85	0.81	0.85

Source	df.	Mean squares: Fresh wt	Mean squares: Dry wt
$\pm$ UVB	2	0.20	0.0376
Error a	2	6.70	0.1695
Irradiance	9	1.21	0.0289
Interaction	18	0.73	0.0169
Error b	27	1.27	0.0163

Fresh weight total observations, 480; $\pm$ UVB, 160; irradiance, 16

Dry weight total observations; 240; $\pm$ UVB, 80; irradiance, 8

TABLE WL-2. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT WHEAT FOLIAGE WT. LAMP EXPOSURE 300 HRS DURING 50 DAYS

UVB LAMP IRRADIANCE		FRESH WT			DRY WT		
		+UVB	-UVB		+UVB	-UVB	
Weighted	Non-weighted	CA	M	U	CA	M	U
$mW.m^{-2}$	$mW.m^{-2}$	g	g	g	g	g	g
4.34	478	7.9	8.6	9.0	2.5	2.5	2.8
3.57	385	8.2	8.2	9.4	2.5	2.6	2.6
2.52	273	9.0	8.4	9.1	2.8	2.7	2.8
1.89	204	8.7	9.3	9.3	2.7	2.9	2.9
1.59	170	9.1	8.6	9.4	2.8	2.9	2.9
1.12	123	8.5	8.5	9.0	2.6	2.8	2.8
0.88	94	8.2	8.9	9.6	2.6	2.8	3.0
0.65	85	9.3	8.3	9.0	2.9	2.6	2.8
0.44	47	8.8	8.2	8.8	2.7	2.6	2.8
0.23	25	8.0	8.5	8.6	2.5	2.7	2.7
$\pm$UVB means		8.6_b	8.6_b	9.1_a	2.7	2.7	2.8

Source	df.	Mean squares: Fresh wt	Mean squares: Dry wt
$\pm$ UVB	2	8.41**	0.69
Error a	2	1.90	0.27
Irradiance	9	1.46	0.17
Interaction	18	1.05	0.08
Error b	27	0.08	0.01

Fresh weight total observations, 240; $\pm$ UVB, 80; irradiance, 8

Dry weight, same

$\pm$ UVB mean separation (within parameter) by LSD, 5% level. Means followed by the same letter are not significantly different.

TABLE WL-3. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT WHEAT PLANT HEIGHT, LAMP EXPOSURE 84 HRS DURING 14 DAYS AND 192 HRS DURING 32 DAYS

UVB LAMP IRRADIANCE		PLANT HT (84 hrs)			PLANT HT (186 hrs)		
		+UVB	-UVB		+UVB	-UVB	
Weighted	Non-weighted	CA	M	U	CA	M	U
$mW.m^{-2}$	$mW.m^{-2}$	cm	cm	cm	cm	cm	cm
4.34	478	14.2	14.3	14.7	27.9	26.6	26.6
3.57	385	14.2	13.9	13.9	25.8	25.8	25.7
2.52	273	13.5	13.7	13.4	26.6	26.4	25.2
1.89	204	14.5	14.0	13.7	26.7	27.8	25.2
1.59	170	13.4	13.5	13.7	25.2	26.2	26.6
1.12	123	13.3	13.7	15.5	24.7	26.6	26.4
0.88	94	14.3	13.5	13.2	25.5	26.4	27.6
0.65	85	13.0	13.7	13.2	24.8	24.7	24.4
0.44	47	13.8	13.9	14.0	25.8	24.7	25.5
0.23	25	13.0	13.5	13.4	24.9	26.2	24.9
± UVB means		13.7	13.8	13.7	25.8	26.1	25.8

Source	df.	Mean squares: Plant ht	Mean squares: Plant ht
± UVB	2	0.28	8.56
Error a	2	1.30	62.22
Irradiance	9	3.15*	34.14
Interaction	18	0.73	16.01
Error b	27	1.29	21.82

Plant height (84 hrs) total observations, 240; ± UVB, 80; irradiance, 8

Plant height (186 hrs) total observations, 720; ± UVB, 240; irradiance 24

TABLE WL-4. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENTS WHEAT PLANT HEIGHT AND HEAD LENGTH, LAMP EXPOSURE 300 HRS DURING 50 DAYS

UVB LAMP IRRADIANCE		PLANT HT			HEAD LENGTH		
		+UVB	-UVB		+UVB	-UVB	
Weighted	Non-weighted	CA	M	U	CA	M	U
$mW.m^{-2}$	$mW.m^{-2}$	cm	cm	cm	cm	cm	cm
4.34	478	42.9	40.7	42.9	4.2	1.5	3.1
3.57	385	39.7	40.6	42.1	1.8	2.5	2.3
2.52	273	38.7	39.3	40.4	1.9	2.2	2.4
1.89	204	39.6	41.4	41.8	1.9	2.1	2.6
1.59	170	40.2	41.8	42.3	2.5	2.4	2.1
1.12	123	39.4	40.0	39.7	2.1	2.8	3.1
0.88	94	39.7	39.1	41.7	2.2	1.9	2.5
0.65	85	40.5	38.7	39.9	3.2	2.4	2.3
0.44	47	39.7	39.8	40.0	2.4	2.2	2.3
0.23	25	36.7	38.9	39.6	1.9	2.0	1.8
± UVB means		39.7	40.0	41.0	2.4	2.2	2.4

		Mean squares	
Source	df.	Plant ht	Head length
± UVB	2	76.2	2.46
Error a	2	67.2	19.86
Irradiance	9	55.7**	4.77
Interaction	18	12.1	4.72
Error b	27	13.9	2.81

Plant height total observations, 480; ± UVB, 160; irradiance 16

Head length, same

TABLE WL-5. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT WHEAT PLANT HEAD AND TILLER PRODUCTION, LAMP EXPOSURE 300 HRS DURING 50 DAYS

UVB LAMP IRRADIANCE		% HEADS			TILLERS/PLANT		
		+UVB	-UVB		+UVB	-UVB	
Weighted $mW.m^{-2}$	Non-weighted $mW.m^{-2}$	CA	M	U	CA	M	U
4.34	478	96.9	49.0	79.2	2.4	3.0	2.6
3.57	385	64.6	77.0	77.1	2.6	2.6	2.6
2.52	273	52.0	57.3	66.7	2.8	2.6	2.6
1.89	204	63.1	66.7	75.0	2.9	2.8	2.8
1.59	170	53.1	67.7	71.9	2.8	2.5	2.7
1.12	123	53.1	77.1	69.8	2.7	2.8	2.6
0.88	94	67.7	64.6	78.1	2.8	2.9	2.9
0.65	85	80.2	72.9	64.6	2.8	2.6	2.8
0.44	47	68.8	70.3	72.9	2.8	2.7	2.7
0.23	25	62.5	77.1	67.7	2.8	2.9	2.5
$\pm$ UVB means		66.2	68.0	72.3	2.7	2.8	2.7

		Mean squares	
Source	df.	% heads	Tillers/plant
$\pm$ UVB	2	1569.69	0.2271
Error a	2	4676.56	0.0521
Irradiance	9	1083.12	0.3336
Interaction	18	1868.39	0.3544
Error b	27	1335.25	0.2956

Percent heads total observations, 480; $\pm$ UVB, 160; irradiance 16

Tillers per plant, same

TABLE PL-1. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT <u>POTATO</u> FOLIAGE WEIGHT, LAMP EXPOSURE 294 HRS DURING 49 DAYS

UVB LAMP IRRADIANCE		FRESH WT			DRY WT		
		+UVB	-UVB		+UVB	-UVB	
Weighted	Non-weighted	CA	M	U	CA	M	U
$mW.m^{-2}$	$mW.m^{-2}$	g	g	g	g	g	g
4.34	478	76.4	72.9	52.4	7.4	7.0	5.5
3.57	385	69.4	67.2	65.4	7.1	7.1	6.7
1.89	204	71.0	66.6	66.2	7.4	6.9	6.7
1.59	170	63.3	69.0	67.5	6.6	6.9	6.9
0.88	94	63.9	64.0	65.2	6.9	6.7	6.9
0.44	47	66.7	61.9	64.8	7.1	6.8	6.7
0.23	25	67.5	64.5	61.4	7.0	6.9	6.5
$\pm$ UVB means		68.3	66.6	63.3	7.1	6.9	6.6

Source	df.	Mean squares: Fresh wt	Mean squares: Dry wt
$\pm$ UVB	2	366.706	3.509
Error a	2	281.841	1.219
Irradiance	6	59.096	0.391
Interaction	12	211.476**	1.202*
Error b	18	51.590	0.385

Total observations for each parameter, 168; $\pm$ UVB, 56; irradiance, 8

TABLE PL-2. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT POTATO TUBER WEIGHT PER PLANT, LAMP EXPOSURE 294 HRS DURING 49 DAYS

UVB LAMP IRRADIANCE		FRESH WT			DRY WT		
		+UVB	-UVB		+UVB	-UVB	
Weighted	Non-weighted	CA	M	U	CA	M	U
$mW.m^{-2}$	$mW.m^{-2}$	g	g	g	g	g	g
4.34	478	142.6	157.9	132.3	28.0	31.0	25.8
3.57	385	153.8	151.3	143.0	31.0	29.6	28.5
1.89	204	155.9	152.1	146.9	31.4	30.5	29.1
1.59	170	147.1	148.7	152.4	29.6	29.2	30.0
0.88	94	153.6	152.7	144.4	30.2	30.3	27.2
0.44	47	155.4	147.9	152.7	30.8	28.9	29.5
0.23	25	150.2	152.1	138.7	29.3	29.6	26.8
$\pm$ UVB means		151.2	151.8	144.3	30.0	29.9	28.1

		Mean squares	
Source	df.	Fresh wt	Dry wt
$\pm$ UVB	2	965.072	62.7935
Error a	2	1021.540	41.8899
Irradiance	6	175.058	12.3421
Interaction	12	264.649	2.3623
Error b	18	208.740	10.7601

Total observations for each parameter, 168;
$\pm$ UVB 56; irradiance, 8

TABLE PL-3. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENTS
POTATO TUBER WEIGHT PER TUBER, LAMP EXPOSURE
294 HRS DURING 49 DAYS

UVB LAMP IRRADIANCE		FRESH WT			DRY WT		
		+UVB	-UVB		+UVB	-UVB	
Weighted	Non-weighted	CA	M	U	CA	M	U
$mW.m^{-2}$	$mW.m^{-2}$	g	g	g	g	g	g
4.34	478	9.3	11.7	15.3	1.8	2.3	3.0
3.57	385	11.3	10.7	10.5	2.3	2.1	2.1
1.89	204	10.8	10.1	11.0	2.2	2.0	2.2
1.59	170	10.8	11.0	13.0	2.2	2.2	2.6
0.88	94	13.0	9.9	15.1	2.5	2.0	3.3
0.44	47	13.3	13.0	13.2	2.6	2.5	2.7
0.23	25	11.8	11.3	11.5	2.3	2.2	2.2
$\pm$ UVB means		11.5	11.1	12.8	2.3	2.2	2.6

		Mean squares	
Source	df.	Fresh wt	Dry wt
$\pm$ UVB	2	45.13	2.0943
Error a	2	7.62	0.5071
Irradiance	6	19.93	0.8593
Interaction	12	16.30	0.8507
Error b	18	10.46	0.5015

Total observations for each parameter, 168; $\pm$ UVB 56;
irradiance, 8

TABLE PL-4. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT POTATO FOLIAGE WEIGHT PER TUBER WEIGHT, LAMP EXPOSURE 294 HRS DURING 49 DAYS

UVB LAMP IRRADIANCE		FRESH WT(ratio)			DRY WT(ratio)		
		+UVB	-UVB		+UVB	-UVB	
Weighted $mW.m^{-2}$	Non-weighted $mW.m^{-2}$	CA	M	U	CA	M	U
4.34	478	0.54	0.46	0.40	0.27	0.22	0.21
3.57	385	0.45	0.45	0.46	0.23	0.24	0.24
1.89	204	0.46	0.44	0.45	0.24	0.23	0.23
1.59	170	0.43	0.46	0.44	0.22	0.24	0.23
0.88	94	0.42	0.42	0.45	0.23	0.22	0.26
0.44	47	0.43	0.42	0.42	0.23	0.23	0.23
0.23	25	0.45	0.42	0.44	0.24	0.23	0.24
$\pm$ UVB means		0.45	0.44	0.44	0.24	0.23	0.23

Source	df.	Mean squares: Fresh wt	Mean squares: Dry wt
$\pm$ UVB	2	0.0043	0.0005
Error a	2	0.0013	0.0005
Irradiance	6	0.0051	0.0003
Interaction	12	0.0082**	0.0002
Error b	18	0.0024	0.0010

Total observations for each parameter, 168; $\pm$ UVB 56; irradiance, 8

TABLE PL-5. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT, POTATO TUBER NUMBER AND STEM NUMBER, LAMP EXPOSURE 294 HRS DURING 49 DAYS

UVB LAMP IRRADIANCE		TUBER NO.			STEM NO.		
		+UVB	-UVB		+UVB	-UVB	
Weighted $mW.m^{-2}$	Non-weighted $mW.m^{-2}$	CA	M	U	CA	M	U
4.34	478	15.3	13.8	9.3	9.3	10.8	7.5
3.57	385	13.8	15.0	14.1	9.3	10.3	9.3
1.89	204	14.8	15.4	14.0	8.5	8.6	8.8
1.59	170	14.9	14.8	13.0	13.8	10.6	7.1
0.88	94	12.4	15.9	9.9	7.9	9.4	7.4
0.44	47	12.1	12.3	12.1	8.5	9.1	7.0
0.23	25	13.4	14.9	12.5	8.1	10.9	9.1
± UVB means		13.8[1] a	14.6 a	12.1 b	9.3	9.9	8.0

Source	df.	Mean squares: Tuber no.	Mean squares: Stem no.
± UVB	2	86.8218*	54.0576
Error a	2	2.1790	13.0779
Irradiance	6	22.5198	16.5258
Interaction	12	15.1920	15.1944
Error b	18	14.0247	26.2596

Total observations for each parameter, 168;
± UVB 56; irradiance, 8

[1] ± UVB mean separation (within parameter) by LSD, 5% level. Means followed by the same letter are not significantly different.

TABLE PL-6. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT, NUMBER OF POTATO TUBERS PER STEM, LAMP EXPOSURE 294 HRS DURING 49 DAYS

UVB IRRADIANCE		TUBERS/STEM		
		+UVB	-UVB	
Weighted $mW.m^{-2}$	Non-weighted $mW.m^{-2}$	CA	M	U
4.34	478	1.7	1.3	1.2
3.57	385	1.6	1.5	1.6
1.89	204	1.8	1.8	1.6
1.59	170	1.7	1.4	1.9
0.88	94	1.6	1.7	1.5
0.44	47	1.5	1.4	1.9
0.23	25	1.8	1.4	1.4
± UVB means		1.7_a[1]	1.5_b	1.6_a

Source	df.	Mean squares Tubers/stem
± UVB	2	0.3157**
Error a	2	0.0010
Irradiance	6	0.2564
Interaction	12	0.3060*
Error b	18	0.1369

Total observations for each parameter, 168;
± UVB 56; irradiance 8

[1] ± UVB means separation (within parameter) by LSD 5% level. Means followed by the same letter are not significantly different.

TABLE RL-1. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT, RADISH FOLIAGE WEIGHT, LAMP EXPOSURE 144 HRS DURING 24 DAYS

UVB LAMP IRRADIANCE		FRESH WT			DRY WT		
		+UVB	-UVB		+UVB	-UVB	
Weighted	Non-weighted	CA	M	U	CA	M	U
$mW.m^{-2}$	$mW.m^{-2}$	g	g	g	g	g	g
4.34	478	2.19	2.63	2.59	0.24	0.31	0.29
3.57	385	1.87	2.20	2.38	0.23	0.26	0.28
2.52	273	2.04	1.92	2.39	0.24	0.23	0.27
1.89	204	1.97	2.00	2.28	0.23	0.24	0.30
1.59	170	2.25	1.93	2.47	0.26	0.22	0.29
1.12	123	2.35	1.98	2.28	0.30	0.23	0.28
0.88	94	2.25	1.86	2.30	0.27	0.22	0.29
0.65	85	2.26	2.09	2.29	0.28	0.24	0.29
0.44	47	2.63	2.08	1.98	0.32	0.24	0.25
0.23	25	2.42	2.18	2.09	0.29	0.26	0.25
$\pm$ UVB means		2.23	2.09	2.30	0.27	0.25	0.28

		Mean squares	
Source	df.	Fresh wt	Dry wt
$\pm$ UVB	2	0.97	0.0216
Error a	2	0.71	0.0167
Irradiance	9	0.27	0.0025
Interaction	18	0.38	0.0068
Error b	27	0.25	0.0044

Total observations for each parameter, 240;
$\pm$ UVB, 80; irradiance, 8

TABLE RL-2. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT
RADISH FOLIAGE WEIGHT, LAMP EXPOSURE 168 HRS
DURING 28 DAYS

UVB LAMP IRRADIANCE		FRESH WT			DRY WT		
		+UVB	-UVB		+UVB	-UVB	
Weighted	Non-weighted	CA	M	U	CA	M	U
$mW.m^{-2}$	$mW.m^{-2}$	g	g	g	g	g	g
4.34	478	3.49	2.98	3.22	0.35	0.28	0.36
3.57	385	2.85	2.63	3.22	0.29	0.29	0.39
2.52	273	2.78	2.67	3.18	0.26	0.25	0.38
1.89	204	3.56	2.96	3.47	0.32	0.29	0.40
1.59	170	3.54	2.26	2.75	0.34	0.23	0.32
1.12	123	3.33	2.11	3.13	0.33	0.33	0.38
0.88	94	2.70	2.90	3.19	0.31	0.28	0.39
0.65	85	3.03	2.81	3.23	0.32	0.27	0.37
0.44	47	3.02	3.00	2.94	0.32	0.30	0.36
0.23	25	3.36	2.97	3.37	0.33	0.31	0.40
± UVB means		3.17	2.83	3.17	0.32	0.28	0.38

		Mean squares	
Source	df.	Fresh wt	Dry wt
± UVB	2	3.08	0.1718
Error a	2	2.06	0.0638
Irradiance	9	0.73	0.0068
Interaction	18	0.48	0.0041
Error b	27	0.25	0.0039

Total observations for each parameter, 240;
± UVB, 80; irradiance, 8

TABLE RL-3. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT, RADISH ROOT WEIGHT, LAMP EXPOSURE 144 HRS DURING 24 DAYS

UVB LAMP IRRADIANCE		FRESH WT			DRY WT		
		+UVB	-UVB		+UVB	-UVB	
Weighted	Non-weighted	CA	M	U	CA	M	U
$mW.m^{-2}$	$mW.m^{-2}$	g	g	g	g	g	g
4.34	478	3.27	4.10	4.20	0.19	0.24	0.26
3.57	385	2.56	3.29	3.54	0.15	0.20	0.23
2.52	273	3.11	2.24	4.18	0.18	0.14	0.25
1.89	204	3.01	2.99	3.62	0.17	0.19	0.23
1.59	170	3.93	2.84	4.01	0.23	0.18	0.25
1.12	123	3.53	2.87	3.87	0.21	0.19	0.24
0.88	94	2.82	2.77	3.49	0.17	0.20	0.22
0.65	85	3.21	2.86	3.04	0.20	0.19	0.20
0.44	47	3.17	2.74	4.21	0.19	0.18	0.25
0.23	25	3.99	2.96	3.28	0.24	0.18	0.21
$\pm$ UVB means		3.26	2.97	3.74	0.19	0.19	0.23

		Mean squares	
Source	df.	Fresh wt	Dry wt
$\pm$ UVB	2	12.30	0.0429
Error a	2	10.20	0.0393
Irradiance	9	1.66	0.0044
Interaction	18	1.57	0.0048
Error b	27	2.14	0.0066

Total observations for each parameter, 240;
$\pm$ UVB, 80; irradiance, 8

TABLE RL-4. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT, RADISH ROOT WEIGHT, LAMP EXPOSURE 168 HRS DURING 28 DAYS

UVB LAMP IRRADIANCE		FRESH WT			DRY WT		
		+UVB	-UVB		+UVB	-UVB	
Weighted	Non-weighted	CA	M	U	CA	M	U
$mW.m^{-2}$	$mW.m^{-2}$	g	g	g	g	g	g
4.34	478	6.23	6.10	8.11	0.44	0.42	0.50
3.57	385	4.70	4.47	5.72	0.34	0.35	0.41
2.52	273	5.57	4.72	6.61	0.37	0.37	0.45
1.89	204	6.50	5.47	4.67	0.47	0.40	0.34
1.59	170	6.28	4.40	6.00	0.44	0.34	0.41
1.12	123	5.92	4.91	6.26	0.41	0.37	0.43
0.88	94	5.70	5.61	6.42	0.41	0.41	0.43
0.65	85	5.07	5.49	5.45	0.38	0.39	0.38
0.44	47	5.59	4.84	5.99	0.41	0.37	0.41
0.23	25	5.41	4.51	6.06	0.39	0.37	0.45
± UVB means		5.70	5.05	6.13	0.41	0.38	0.42

		Mean squares	
Source	df.	Fresh wt	Dry wt
± UVB	2	23.51	0.0369
Error a	2	1.71	0.0115
Irradiance	9	5.70	0.0127
Interaction	18	2.86	0.0096
Error b	27	3.88	0.0130

Total observations for each parameter, 240;
± UVB, 80; irradiance, 8

TABLE RL-5. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT, RADISH FOLIAGE WT PER ROOT WT, LAMP EXPOSURE 144 HRS DURING 24 DAYS

UVB LAMP IRRADIANCE		FRESH WT			DRY WT		
		+UVB	-UVB		+UVB	-UVB	
Weighted $mW.m^{-2}$	Non-weighted $mW.m^{-2}$	CA	M	U	CA	M	U
4.34	478	1.34	1.47	1.16	0.69	0.75	0.63
3.57	385	1.62	1.58	1.58	0.77	0.93	0.92
2.52	273	1.48	1.81	1.11	0.80	1.04	0.59
1.89	204	1.49	1.47	1.56	0.72	0.75	0.78
1.59	170	1.22	2.14	1.51	0.61	1.45	0.84
1.12	123	1.52	1.24	1.94	0.76	0.72	0.84
0.88	94	2.64	1.50	2.28	1.51	1.67	1.18
0.65	85	1.68	1.62	1.45	0.86	1.00	0.76
0.44	47	1.78	2.29	1.99	0.91	1.66	0.96
0.23	25	1.30	1.46	1.79	0.66	0.81	0.96
± UVB means		1.61	1.66	1.64	0.83	1.08	0.85

		Mean squares	
Source	df.	Fresh wt	Dry wt
± UVB	2	1.58	0.057
Error a	2	1.83	1.105
Irradiance	9	1.29	1.522
Interaction	18	0.30	0.865
Error b	27	0.64	1.059

Total observations for each parameter, 240;
± UVB, 80; irradiance, 8

TABLE RL-6. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT, RADISH FOLIAGE WT PER ROOT WT, LAMP EXPOSURE 168 HRS DURING 28 DAYS

UVB LAMP IRRADIANCE		FRESH WT			DRY WT		
		+UVB	-UVB		+UVB	-UVB	
Weighted $mW.m^{-2}$	Non-weighted $mW.m^{-2}$	CA	M	U	CA	M	U
4.34	478	0.57	0.54	0.44	0.81	0.69	0.73
3.57	385	0.69	0.65	0.57	0.96	0.87	0.94
2.52	273	0.51	0.57	0.57	0.72	0.67	0.93
1.89	204	0.63	0.56	0.83	0.75	0.75	1.23
1.59	170	0.60	0.58	0.51	0.80	0.74	0.92
1.12	123	0.58	0.66	0.54	0.81	0.94	0.91
0.88	94	0.58	0.55	0.57	0.95	0.70	1.01
0.65	85	0.63	0.55	0.60	0.89	0.71	0.98
0,44	47	0.63	0.79	0.53	0.88	0.96	0.94
0.23	25	0.70	0.69	0.62	0.88	0.86	0.98
± UVB means		0.61	0.61	0.58	0.85	0.79	0.96

		Mean squares	
Source	df.	Fresh wt	Dry wt
± UVB	2	0.032	0.586
Error a	2	0.057	0.775
Irradiance	9	0.068	0.100
Interaction	18	0.047	0.084
Error b	27	0.055	0.087

Total observations for each parameter, 240;
± UVB, 80; irradiance, 8

TABLE PEL-1. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT, PEA FOLIAGE WEIGHT, LAMP EXPOSURE 138 HRS DURING 23 DAYS

UVB LAMP IRRADIANCE		FRESH WT			DRY WT		
		+UVB	-UVB		+UVB	-UVB	
Weighted	Non-weighted	CA	M	U	CA	M	U
$mW.m^{-2}$	$mW.m^{-2}$	g	g	g	g	g	g
3.83	416	3.8	3.8	4.9	0.51	0.52	0.68
3.22	348	4.1	3.7	3.9	0.55	0.50	0.54
2.52	273	3.9	4.1	4.6	0.52	0.56	0.63
1.89	204	4.2	4.0	4.3	0.55	0.54	0.56
1.59	170	3.7	3.9	4.1	0.49	0.53	0.56
0.88	94	4.5	3.6	3.6	0.59	0.48	0.50
0.44	47	3.5	4.4	4.6	0.48	0.62	0.66
± UVB means		3.9	3.9	4.3	0.53	0.54	0.59

		Mean squares	
Source	df.	Fresh wt	Dry wt
± UVB	2	2.38	0.0608
Error a	2	0.95	0.0188
Irradiance	6	0.50	0.0135
Interaction	12	1.13	0.0244
Error b	18	1.19	0.0261

Total observations for each paramter, 168;
± UVB 56; irradiance, 8

TABLE PEL-2. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT, PEA FOLIAGE WEIGHT, LAMP EXPOSURE 168 HRS DURING 28 DAYS

UVB LAMP IRRADIANCE		FRESH WT			DRY WT		
		+UVB	-UVB		+UVB	-UVB	
Weighted	Non-weighted	CA	M	U	CA	M	U
$mW.m^{-2}$	$mW.m^{-2}$	g	g	g	g	g	g
3.83	416	5.8	6.4	8.1	0.96	1.01	1.26
3.22	348	6.3	6.7	7.0	1.02	1.03	1.10
2.52	273	7.3	6.6	7.3	1.15	1.01	1.13
1.89	204	7.4	7.0	7.3	1.17	1.13	1.14
1.59	170	6.8	6.5	7.5	1.06	1.03	1.19
0.88	94	6.8	6.5	6.5	1.14	1.04	1.05
0.44	47	6.9	6.0	7.5	1.13	0.99	1.23
± UVB means		6.8^{1}_{b}	6.5_{b}	7.3_{a}	1.09^{1}_{b}	1.03_{c}	1.16_{a}

Source	df.	Mean squares: Fresh wt	Mean squares: Dry wt
± UVB	2	9.38*	0.2196*
Error a	2	0.28	0.0034
Irradiance	6	1.24	0.0243
Interaction	12	2.02	0.0440
Error b	18	1.04	0.0190

Total observations for each parameter, 168;
± UVB 56; irradiance, 8

[1] ± UVB mean separation (within parameter) by LSD, 5% level. Means followed by the same letter are not significantly different.

TABLE PEL-3. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT, PEA PLANT HEIGHT, LAMP EXPOSURE 138 HRS DURING 23 DAYS

UVB LAMP IRRADIANCE		PLANT HEIGHT		
		+UVB	-UVB	
Weighted	Non-weighted	CA	M	U
$mW.m^{-2}$	$mW.m^{-2}$	cm	cm	cm
3.83	416	23.0	23.4	25.4
3.22	348	22.6	21.2	22.4
2.52	273	24.0	23.3	24.1
1.89	204	24.0	22.8	23.9
1.59	170	23.1	20.5	23.1
0.88	94	21.5	21.2	22.0
0.44	47	22.1	24.3	25.6
± UVB means		22.9	22.4	23.8

		Mean squares
Source	df.	Plant height
± UVB	2	28.80
Error a	2	9.29
Irradiance	6	25.78
Interaction	12	6.50
Error b	18	9.93

Total observations for each parameter, 168;
± UVB 56; irradiance, 8